UTILIZATION OF TEXTILE SLUDGE AS A PARTIAL REPLACEMENT OF CEMENT ON THE PROPERTIES OF CEMENT MORTAR

A dissertation submitted

In partial fulfillment of the requirements

For the degree of

MASTERS OF ENGINEERING

IN

STRUCTURAL ENGINEERING

SUBMITTED BY

SUJANT JHA

(ROLL NO. 801524029)

UNDER THE GUIDANCE OF

Dr. RAFAT SIDDIQUE	**Dr. SHWETA GOYAL**
Senior Professor	Associate Professor
Civil Engineering Department	Civil Engineering Department

THAPAR UNIVERSITY, PATIALA 147004

JULY 2017

DECLARATION

I, hereby declare that the thesis **"Utilization of textile sludge as a partial replacement of cement on the properties of cement mortar"** which is submitted in partial fulfillment of the requirement for the award of the degree of **Master of Engineering** in **Structural Engineering** in the Department of Civil Engineering (CED), Thapar University, Patiala. It is an authentic record of my own independent and original research work carried out by me under the supervision and guidance of **Dr. Rafat Siddique,** Senior Professor, Department of Civil Engineering,Thapar University, Patiala and **Dr. Shweta Goyal,** Associate Professor, Department of Civil Engineering, Thapar University, Patiala.

The matter embodied in this thesis has not been submitted in part or fully to any other university or institute for the award of any degree.

Date: 31/07/2017

Sujant Jha

Roll No. 801524029

CERTIFICATE

This is to certify that the above declaration made by the student concerned is correct to the best of my knowledge and belief.

Dr. Rafat Siddique
Senior Professor
Department of Civil Engineering
Thapar University, Patiala

Dr. Shweta Goyal
Associate Professor
Department of Civil Engineering
Thapar University, Patiala

ACKNOWLEDGEMENTS

The key elements concentration, dedication, hard work and application are not the only essential factors for achieving the desired goals but also guidance, assistance and co-operation of people is necessary.

It gives me immense pleasure to express my sincere and deep gratitude to Dr. Rafat Siddique, Senior Professor (Structural Engineering), Civil Engineering Department, Thapar University, Patiala, and Dr. Shweta Goyal, Associate Professor (Structural Engineering), Civil Engineering Department, Thapar University, Patiala, for valuable guidance and time for reviewing the draft of this dissertation and excellent feedback and suggestions that helped to shape my research skills, constructive criticism and concrete suggestions throughout the course of this work. I owe a debt of gratitude to their for pain taking efforts, constructive ideas, valuable assistance and profuse encouragement that enabled me to complete this dissertation and fulfilment of a wish and a dream, cannot be put to words. Without keen professional insight and critical suggestions, this dissertation would not have been possible.

I would like to thank most warmly to the Dr. Naveen Kwatra, Professor and Head, Civil Engineering Department as well as other faculty members for their co-operation and help provided to me during the course of my studies.

The pliant suggestions; congenial environment offered, help extended and co-operation rendered by the laboratory staff of Structural Engineering Lab, R.C.C. Lab and Library staff have had a definitely positive impact on the essence of this thesis and is duly acknowledged.

Finally, I offer my most significant thanks and love to my family and friends without whom I am nothing, for providing the endless help, understanding me and giving me constant support whenever needed throughout my thesis work. Above all, I thank God for his blessing and giving me the strength and power to make this happen.

Sujant Jha

ABSTRACT

Cement mortar is a building material which is prepared by homogenous mixing of cement and sand with appropriate amount of water. Cement mortars are used for plastering on the exposed surface of masonry, binding building blocks and bedding layer for building block.

Textile sludge is an industrial bi-product which is obtained by treating the liquid waste during various wet processes in textile industry i.e. yarn production, weaving, knitting, dyeing, printing, finishing at common effluent treatment plant or effluent treatment plant. The traditional disposal technique of sludge leads to many negative impact on the environment. Due to the presence of toxic element textile sludge is considered to be hazardous to human health and bio-life. The objective of the research is to evaluate the possibility of utilizing effluent treatment plant sludge in cement mortars. The consistency, initial and final setting time, soundness and fluidity properties of cement by partial replacement of textile sludge are studied. In addition, hardened properties of the resultant mix (compressive strength and split tensile strength), and durability properties (water absorption, rapid chloride penetration test, shrinkage and sorptivity) were investigated. The microstructure of the mix was analyzed by SEM and XRD.

It was observed that up to 5 % replacement of cement with textile sludge, the compressive strength is nearer to the control mix, after that compressive strength decreases gradually. Similar trend was observed for split tensile strength. The rapid chloride penetration resistance increases at 5% replacement level and upto 10%, it was similar to control mix and penetration resistance decrease at higher replacement level. The water absorption, sorptivity and drying shrinkage increases with increase in replacement level of textile sludge. The partial replacement of cement with textile sludge causes an increase in initial and final setting time of mixture. XRD analysis shows that textile sludge is an inert material and SEM images shows that at higher replacement level of cement with textile sludge leads to porous microstructure in mortar which ultimately causes decrease in compressive strength.

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INTRODUCTION

1.1 General

Human beings have been using mortar from ancient period. Around 3000 BC the ancient Egyptian used the mud with straw to form bricks. Around 4000 BC Egyptians used lime mortars and gypsum in the building of pyramid. Most of the structure constructed before 1900 AD in Europe and in Asia are built from lime mortars. Lime mortars have been used for construction in Roman Empire. The cement mortar was developed by mixing cement sand and water. It was developed in the middle of 19th century. This type of mortar was strongest of that period produced by scientist and researchers. This mortar got its popularity in the late 19th century. The use of lime mortar was suppressed by cement mortar for construction work. The main purpose of using cement mortar is due to quick setting and hardening time, time which allows for faster rate of construction. Mortar is defined as the paste which is prepared by homogeneous mixing of binding agent cement, lime and sand with appropriate amount of water. The material and fine aggregate are responsible for the strength and durability of mortar. Mortar is suspension of fine aggregate particle in the paste. The reason behind using mortar in construction is it has good adhesive property, with which it binds building units such as brick stone. Mortars have good fire resistant capacity. Mortar is used for plastering on the exposed surface of masonry. It is also useful to form a bedding layer for building block. Also, Mortars are respectively cheaper than concrete and easily workable.

Cement is extremely important and necessary building material in construction works. Cement is a building material having cohesive as well as adhesive properties in presence of water. In civil engineering construction, the main purpose is to bind fine aggregate (sand) and coarse aggregate particles together to a hard compact durable mass. According to the UNEP Global Environmental Alert Service (GEAS) cement is being used in 150 countries and the consumption is 3.7 billion tons in 2012. Cement consumption in the world has increased three times in last 20 years from 1.37 billion tons of cement in 1994 to 3.7 billion tons of cement in 2012, due to rapid increase in economic growth in Asia. China consumed about 58% of cement produced in the year 2012. In India cement consumed about 6.75% of total cement produced in year 2012

(UNEP 2014)**.** The consumption of cement is increasing every year. The raw materials of cement production are obtained from mining of limestone and sand. All these material becoming exhausted, the cost of it is increasing. The cement industry also produce large amount of carbondioxide. Producing one ton of Portland cement releases one ton of CO_2 to the atmosphere. A lot of research has been carried out to find alternatives to cement, for the sustainable process and product. The industrial by-products have been investigating by various researchers in the recent years. These wastes material has been used as partial and fully replacement of cement as per strength and durability requirement. Most of studies in recent years show that fly ash (from coal burning power station). Silica fume, ground granulated blast furnace slag (from the steel industry), metakolin, scrap tire rubber, baggase ash can be used in concrete as a partial replacement of Ordinary Portland Cement. In addition to this iron slag, copper slag, waste foundry sand can be used in concrete as partial replacement of sand.

The use of supplementary cementing material reduces the quantity of clinker for production of cement, as a result of which there is a significant reduction in greenhouse gases emission. The use of these industrial by-products in concrete helps to improve fresh and hardened properties. The supplementary cementing materials are of different properties which allow engineers to choose for the different application. The use of the industrial by-products reduces the consumption of natural resources as well as dispossable problem of the material. As the cement is replaced by the industrial by-products it makes mortar economical. Some industrial by-products not only have a disposal problem they also threat to human and other bio life due to toxic elements present in it. Such industrial by-products may be regarded as hazardous waste.

1.2 Textile Sludge

Textile sector is persisting from an earlier time in India. It is largest sector in India. As per an estimate total amount of solid waste generated each year is about 960 million tons, out of which share of inorganic waste is about 350 million tons, while that of inorganic waste is 290 million tons. About 4.5 million tons of solid waste obtained from industrial and mining sector can be considered as hazardous (Pappu et al. 2007). Textile sector in India is among the top foreign exchange in the economy sectors. About 21,076 units are distributed throughout the country (Bal 1999). The world is facing serious problem in disposing the waste. Textile industry is one of the major polluting sectors in India. The treatment plants are facing problems regarding sludge accumulation and generation. Due to chemical and mineral content present in textile sludge these are considered as hazardous in nature. Improper disposing of these solid wastes has detrimental effect on human beings. Solid waste management should be taken into account into consideration with higher priority before the situation becomes too complicated. The traditional disposal technique of sludge such as land filling, agricultural uses, open dumping burning method are found to have some negative impacts such as land losses the fertility, contamination of underground water, requirement of large area. The leachate from landfilling and incineration induces secondary pollution.

Textile industry uses large amount of water chemical for wet processing of textile. The major processes involved in wet processing are yarn production, weaving, knitting, leaching, dyeing, printing and finishing. Almost 70-75% of the water is required for dyeing and finishing stage. The effluent composition and volume generated are high. The major pollutants present in the textile waste are colour, suspended solids, toxicants, detergents, chlorinated compounds, chemicals, organic matter, inorganic matter and dissolved solid. Generally the dyes present in the textile waste which is major source of waste generation are azo dyes, acidic dyes. These dyes get easily washed during the processing of textile. About 50% of initial dye load gets washed off as an effluent during dyeing process. In such situation proper management of textile waste has become important.

Solidification and stabilization techniques are used for the proper management of textile waste. Solidification and stabilization is process of treating the waste containing various harmful by-product i.e. colour, dyes, toxicants etc and prevent them from direct exposing to the environment. Solidification is the process in which the liquid waste generated is minimized by converting into solid form. The migration of contaminant is restricted by decreasing the surface area exposed to leaching. Stabilization is the technique which reduces the impurities concentration of waste water to least toxic and soluble. These techniques are used for treatment of sludge, toxic metals, and organic constituent. The common adsorbents used for solidification and stabilization are lime, ordinary portland cement. The various pozzolona, agricultural waste can also be used as binder such as rice husk ash, slow dust, coir-pith, fly ash, baggase ash. The other absorbents are activated carbon, silica gel, activated aluminium among the activated carbons mostly used. Thus the sludge obtained by treating the waste water by treatment process of chemical coagulation (i.e. by addition of aluminium/iron/magnesium salt and lime) and on separation from liquid form.

Due to the environmental constraints, it becomes important to obtain the substitute for traditional building material in construction industry. The use of textile sludge in building and construction material not only converts waste to useful by-product but also helps in the elimination of disposal problem. Natural resources are being conserved.

1.3 Properties of Textile Sludge

Physical and chemical properties of textile sludge used in different studies are given in Table 1.1 and Table 1.2 respectively.

1.3.1 Physical Properties of Textile Sludge

From Table 1.1 it can be observed that Specific gravity of textile sludge varies from 0.94 to 2.38 and pH value indicates it is alkaline in nature. There is also a huge variation in moisture content. It can be concluded that the variation in property of it is due to difference in source from which it is collected.

Table 1.1: Typical Physical Properties of Textile Sludge

Properties	**Values**							
	Baskar et al. (2006)	**Begum et al. (2013)**	**Joo-hwa (1987)**	**Patel and Pandey (2012)**	**Weng and Chiang (2003)**	**Juel et al. (2017)**	**Zhan and Poon (2015)**	**Bala subramaniam et al. (2006)**
Specific gravity	2.32	2.21	2.38	0.94	1.75	-	1.14	2.4
pH	-	7.14	8.30	8.70	7.27	7.5±0.2	-	9.13
Moisture (%)	-	3.34	60	10.50	41	70±8.34	75.24	28.72
Colour	Brown	-	-	-	-	-	-	-
Appearance	Agglomerated fine solid	-	-	-	-	-	-	-

1.3.2 Chemical Properties of Textile Sludge

Chemical composition of textile sludge used by various researchers shows that the main elements present in it are CaO and Fe_2O_3. It also contains traces of SiO_2, Al_2O_3 and MgO, TiO_2, P_2O_5, SO_3 and SO_4.

Table 1.2: Typical Chemical Properties of Textile Sludge

Properties	**Chemical composition (%)**			
	Baskar et al. (2006)	**Juel et al. (2017)**	**Zhan and Poon (2015)**	**Cheriaf et al. (2015)**
CaO	28.4	26.26	0.87	1.7
Fe_2O_3	9.1	34.32	60.45	0.1
SiO_2	7.1	3.55	3.40	2.9
Al_2O_3	0.698	0.48	6.20	10.3
MgO	-	1.69	-	0.8
TiO_2	-	0.41	0.53	0.4
P_2O_5	-	-	2.79	4.8
SO_3	-	28.71	-	-
SO_4	-	-	24.95	-
LOI	-	-	11.81	76.4

1.3.3 X-ray Diffraction of Textile Sludge

The X-ray diffraction pattern of textile sludge in Figure 1.1 shows that the compounds like calcite ($CaCO_3$), vaterite ($CaCO_3$), calcium hydroxide $Ca(OH)_2$, gypsum ($CaSO_4(H_2O)_2$). The presence of these compounds confirms the possibility of using textile sludge in concrete and mortars.

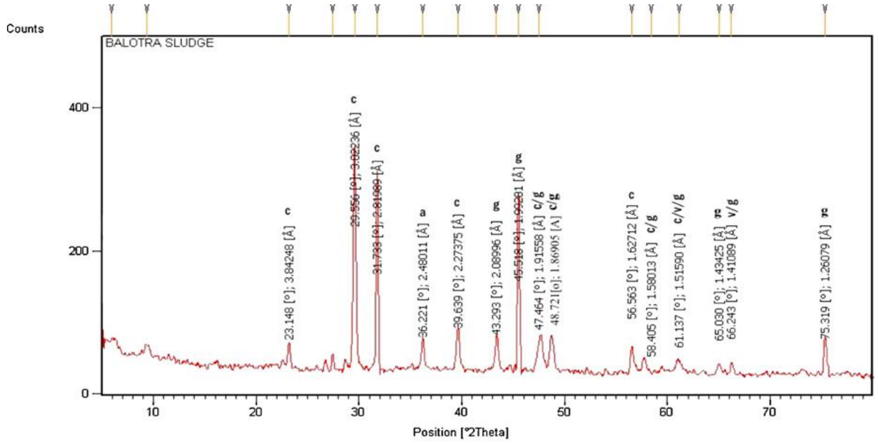

Fig. 1.1: XRD Pattern of Textile Sludge from Balotra CETP.
(Patel and Pandey 2012)

1.3.4 Scanning Electron Microscopy of Textile Sludge

The scanning electron micrograph of sludge is shown in Figure 1.2. The appearance of textile sludge shows agglomerated particles. The majority of particles are spherical in shape.

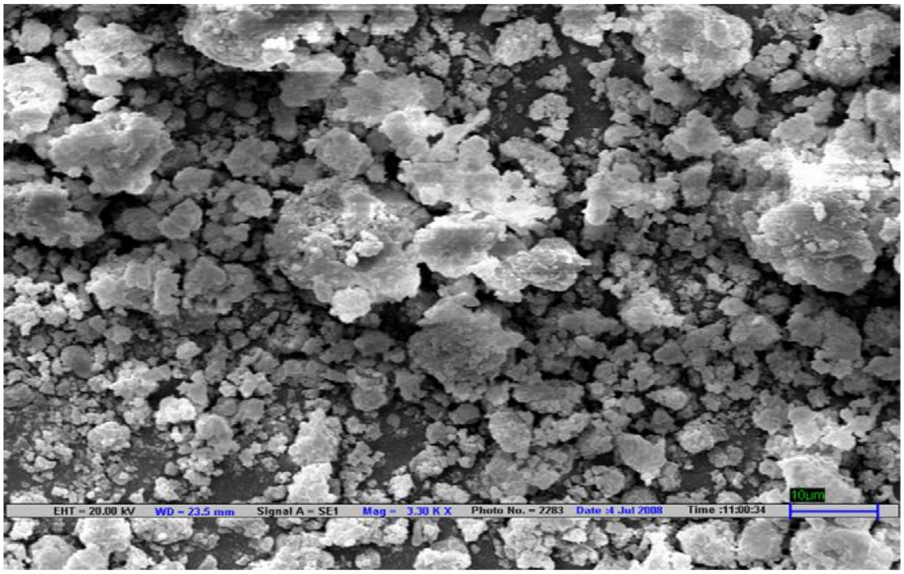

Fig. 1.2 : SEM of Sludge from Balotra CETP (at 3300x Magnification).
(Patel and Pandey 2012)

1.4 Scope and Objective of Present Work

The primary objective of this study is to evaluate the possibility of utilizing textile sludge as a partial replacement of cement. In the present study, cement sand mortars have been prepared by replacement of cement with variable percentages of textile sludge. Following are the main objectives of this study.

- To compare the compressive strength, split tensile strength of control mix and the mix obtained by partially replacing cement with textile sludge from 0% to 20% at 5% intervals.
- To determine the durability properties i.e. water absorption, rapid chloride penetration test, sorptivity and shrinkage of textile sludge incorporated mortars.
- To find out the optimum amount of cement replacement with textile sludge, so as to meet strength and durability requirements of the cement mortars.

1.5 Outline of Thesis

This thesis report includes five chapters:

Chapter 1: Introduction gives general aspects about cement mortar, significance of using industrial by-products as cement replacement. Also production, processing, and properties of textile sludge are included.

Chapter 2: Literature review gives an overview of previously published literature on the use of textile sludge as partial cement replacement in mortars, concrete blocks and building materials.

Chapter 3: Experimental program gives details about different ingredients used for preparing mortar and their physical properties, mix proportioning of mortar. Mixes and methodology of various test to be performed on mortar mixes to evaluate its fresh hardened and durability properties.

Chapter 4: This chapter includes the results and analysis of fresh properties of mortar, hardened property (compressive strength and split tensile strength), durability properties (water absorption, RCPT, sorptivity, shrinkage) and characterization techniques (XRD and SEM) incorporating is as partial replacement of cement in mortar and results are compared to control mortar.

Chapter 5: This chapter gives major conclusions arising in results and discussions.

References

CHAPTER 2

LITERATURE REVIEW

2.1 General

This chapter covers literature review of utilizing textile sludge as partial replacement of cement, fine aggregate, clay. Various literatures have focused on manufacturing of concrete blocks, mortars, and bricks. The main objective of this review is to have knowledge regarding utilization of textile sludge in structural, non-structural application. Studies are carried out in terms of fresh hardened and durability properties. Different properties studied in the literature review are consistency, initial setting time, final setting time, bulk density, compressive strength, water absorption, shrinkage and loss of ignition.

2.2 Utilization of Textile Sludge in Concrete and Mortar

This section includes the summary of literatures available on utilization of textile sludge in concrete and mortar.

2.2.1 Consistency

Balasubramanian et al. (2006) studied the utilization of textile sludge in the construction material. The effect of partial replacement of cement with textile sludge at a replacement level of 5, 10, 15, 20, 25, 30 and 35% respectively. They observed that the control mix has lowest consistency of 31% and consistency limit of cement sludge mixture goes on increasing with increase in replacement percentage of textile sludge. For the replacement level of 35% there is an increase in consistency by 9% due to increase in water demand required for mixing.

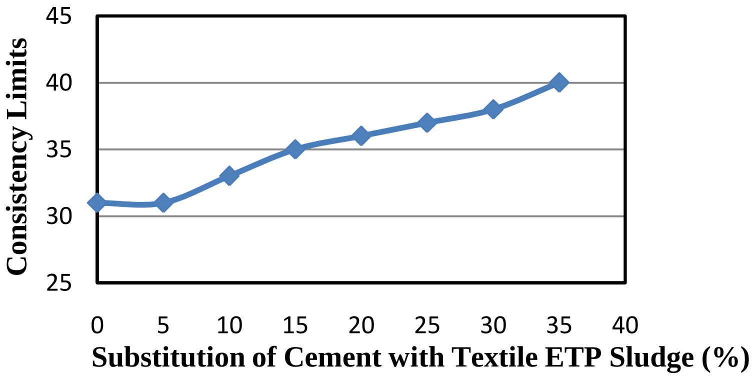

Fig. 2.1: Consistency Limits for Mixture of Cement and Textile ETP Sludge.

(Balasubramanian et al. 2006)

Patel and Pandey (2012) studied the effect of partial replacement of portland pozzolona cement with textile sludge from waste water plants. The replacement percentages were 30, 40, 50, 60 and 70% respectively. They observed that there is increase in water requirement for mixing on the inclusion of textile sludge. The increase in water requirements 9.42, 17.85, 35.71, 52.85 and 57.14% for 30, 40, 50, 60 and 70% textile sludge replacement.

Cheriaf et al (2015) studied the solidification and stabilization of textile sludge with portland cement. The textile sludge was used as partial replacement of cement at replacement level 10, 20, 30 and 40% respectively. They observed that the water/binder ratio increases with the inclusion of textile sludge. The water binder ratio were found to be 0.30, 0.38, 0.40 and 0.45 for 10, 20, 30, and 40% textile sludge replacement. They concluded that the water/binder ratio increases due to the increase in water demand.

2.2.2 Initial and Final Setting Time

Balasubramanian et al. (2006) the studied utilization of textile sludge in the construction material. They concluded that the presence of organic matter in the textile sludge causes decrease in the setting time. They also reported that there was more delay at 30% replacement level in setting process of building components.

2.2.3 Compressive Strength

Balasubramanian et al. (2006) investigated the effect of incorporation of textile sludge with replacement of cement on compressive strength of mortar. They investigated the effect of 5, 10, 15 and 20% replacement of cement with textile sludge at an age of 3, 7, 28 days respectively. The water cement ratio was varied from 0.45 to 0.7 for cement and variable percentages of textile sludge/cement. The cement sand ratio was kept 1: 3. The results of the compressive strength test of the textile sludge mortar are presented in Figure 2.2. They concluded that at a replacement level of 5% the compressive strength is nearer to the control mix. For the concrete block having more than 5% sludge content there is gradual decrease in compressive strength.

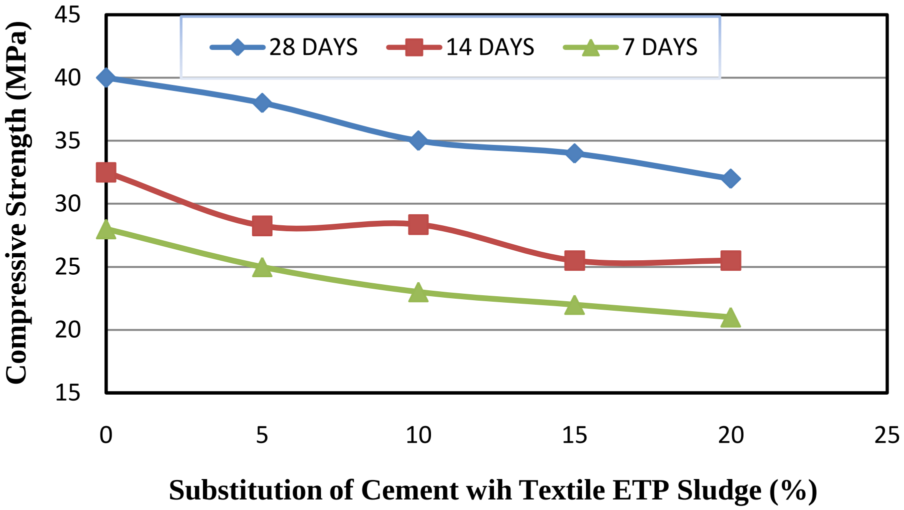

Fig. 2.2: Compressive Strength for Mixture of Cement and Textile ETP Sludge. (Balasubramanian et al. 2006)

Patel and Pandey (2012) investigated the utilization of textile sludge in cement sludge blocks. The substitution percentages of cement with textile sludge are 30, 40, 50, 60 and 70% respectively. They observed that the compressive strength of cement sludge blocks were lower than that of control mix at all the ages. After 28 days of curing, the compressive strength lies between 3.62-33.7 MPa. They reported that the decrease in the compressive strength might be like due to the presence of salts like zinc, lead which causes decrease in hydration reaction required for the strength development. These salts form a membrane around the cement particles which prevents transportation of water and ion required for cement hydration.

Cheriaf et al. (2015) investigated the effect of incorporation of textile sludge as a partial replacement of cement on compressive strength of textile sludge in cement sludge blocks. The results of the compressive strength test of the textile cement sludge blocks are presented in Figure 2.3. There is sharp increase in compressive strength at 28 days of cement sludge sample with 30% cement replacement having compressive strength higher than 30 MPa. Similarly for 40% cement replacement level with textile sludge there is drastic decrease in early strength but after 90 days of hydration the strength is increased from 2 MPa -17 MPa. They concluded that the increase in strength at later ages is due to pozzolonaic effect of textile sludge.

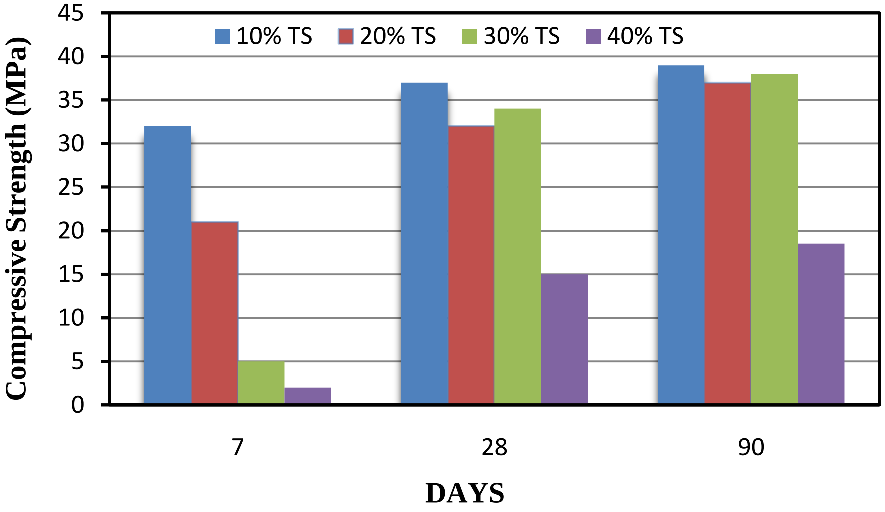

Fig. 2.3: Compressive Strength of Mixtures Containing Plain Cement and Textile sludge. (Cheriaf et al. 2015)

Zhan and Poon (2015) investigated the effect of replacement of fine aggregate with textile sludge on the compressive strength of concrete block. The replacement level was 10, 15, 20 and 30% respectively. They observed that when the oven dried textile sludge was used for making concrete blocks without lime treatment there is no significant increase in compressive strength from 7days to 28 days. The obtained sludge was mixed with lime in a proportion of 1:0.07 and mixture was left for 24 hours before casting the concrete blocks. They observed that there is a sharp increase in compressive strength from 7 days to 28 days. For the 15% replacements the compressive strength increases from 5.9 MPa to 28.7 MPa and for 20% replacement the compressive strength increases from 2.9 MPa to 23.3 MPa. The compressive strength for control mix and 10% replacement by textile sludge after 28 days have 52.1 MPa, 43.3 MPa respectively. The compressive strength was decreasing with increase in sludge content. The compressive strength decreases by 8.8, 23.4, 28.8% for replacement of 10, 15 and 20% respectively. They concluded that the presence of ammonia in the textile sludge might decrease the compressive strength of concrete block. Furthermore due to the presence of ammonia in fresh concrete mixture suppresses the formation of calcium silicate hydrate and ettringite which are important for cement hydration on of textile sludge.

2.3 Utilization of Textile Sludge as Brick

This section includes the summary of literatures available on utilization of textile sludge in brick.

2.3.1 Compressive Strength

Weng et al. (2003) investigated the compressive strength of brick replacing clay with textile sludge as substitution percentage of 10, 20, 30 and 40% respectively. The compressive strength was determined as per CNS 1999. The result of compressive strength is presented in Figure 2.4. The compressive strength of textile sludge brick is dependent on the amount of sludge added and firing temperature. The maximum compressive strength was achieved at 10% replacement level, subjected to a temperature of 1000°C. When 20% clay was replaced by sludge at a firing temperature of 1000°C satisfies the compressive strength requirement of first class brick as per Chinese National Standard (CNS). Similarly, when there is 30% replacement of clay by sludge it satisfies the requirement of second class brick.

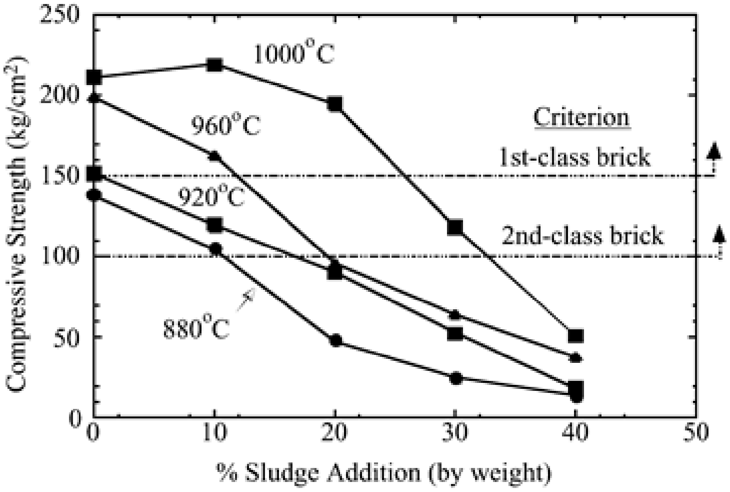

Fig. 2.4: The Compressive Strength of Bricks. (Weng et al. 2003)

Bhaskar et al. (2006) investigated the effect of replacement of clay with textile sludge on compressive strength of brick at a replacement level of 3 to 30% with an increment of 3%. The compressive strength was determined as per IS 3495(Part I):1992. The results of the compressive strength test of the bricks are presented in Figure 2.5. They observed that the compressive strength of brick was decreased on the addition of textile sludge. The maximum amount of sludge that can be added was 6 to 9% which satisfy the requirement of first class, second class brick. They reported that the reference brick have strength of 6.5 MPa whereas with 6 and 9%

replacement has compressive strength of 4.25 MPa, 3.54 MPa, when fired at temperature of 800°C (for 8 hours). They observed that the firing temperature and firing time causes increase compressive strength of brick. When 9% sludge amended bricks are subjected to a temperature of 25°C for 8 hours the compressive strength was found to be 0.92 MPa whereas with increase in temperature 200°C, 400°C, 600°C and 800°C the compressive strength was 1.64 MPa, 2.07 MPa, 3.06 MPa, 3.65MPa. Similarly when bricks are subjected to a constant temperature of 800°C with increase in firing time in hours the brick with 8 hours firing time shows maximum compressive strength of 3.48 MPa, followed by 2.5MPa, 1.69 MPa and 1.14 MPa for 6 hours, 4 hours, 2 hours whereas for non fired brick the compressive strength was 0.85 MPa. They concluded that upto 80% of compressive strength was obtained when bricks fired beyond 400°C.

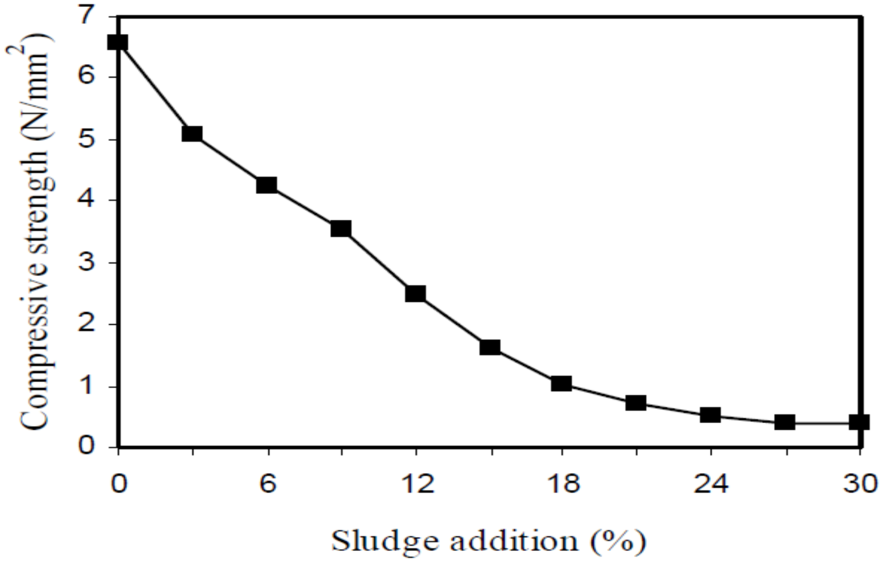

Fig. 2.5: Effect of Sludge Addition on Compressive Strength of Bricks (fired at 800°C for 8 hours). (Bhaskar et al. 2006)

Begum et al. (2013) investigated the compressive strength of brick replacing clay with textile sludge at a substitution of 3, 6, 9, 15, 20, 30 and 50% respectively at a curing age of 1 day, 7 days. The compressive strength was determined as per IS 3495(Part I) 1992. The results of the compressive strength test of the bricks are presented in Figure 2.6. They observed that there is increase in compressive strength at 7 days of curing as compared to 1 day of curing. They reported that the water immersion plays an important role in the increment of compressive strength. The compressive strength of brick was decrease with increase in replacement of clay with sludge. They found that the compressive strength of brick after 7 days of water curing was 8 MPa and 2.5 MPa for reference brick and 50% textile sludge amended brick. They concluded that the decrease in strength is due to increase in pore volume of brick. The sludge contains more organic matter which results in increase in pore volume. However upto 15% clay substituted sludge amended bricks satisfy the strength requirement of first class brick. Similarly upto 30% replacement of clay with sludge amended bricks satisfy the compressive strength requirement of second class brick.

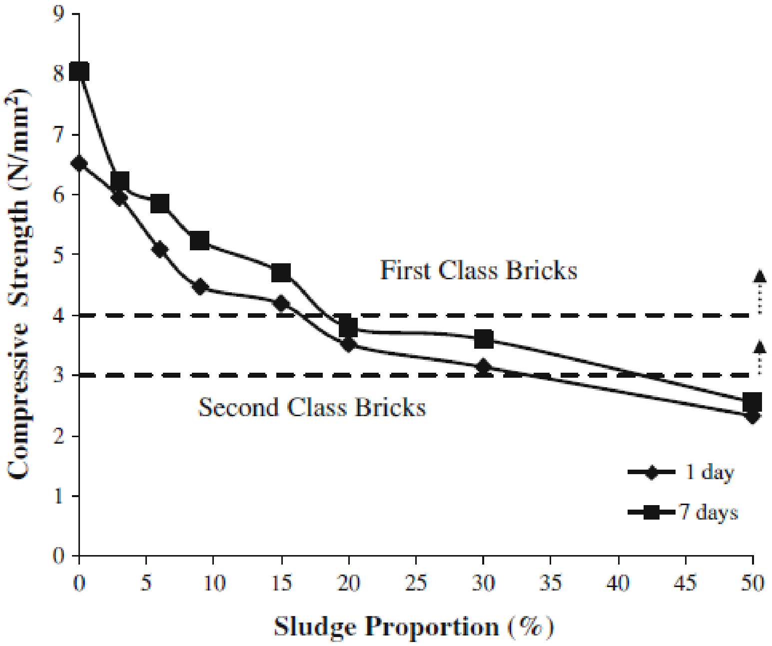

Fig. 2.6: Compressive Strength of Brick after 1 and 7 days Immersion in Water. (Begum et al. 2013)

Juel et al. (2017) investigated the effect of replacement of clay with sludge obtained from leather industry on compressive strength of brick at a replacement level of 10, 20, 30 and 40% respectively. The compressive strength was determined as per BDS 208 (2009). The results of the compressive strength test of the bricks are presented in Figure 2.7. There was decrease in compressive strength by 19, 31, 48 and 56% for 10, 20, 30 and 40% sludge brick compared with reference brick, fired at 1000°C. when the brick prepared by replacing clay by 10% sludge at a temperature of 950°C and 1000°C satisfy the requirement of Grade-S brick, 20-30% sludge amended bricks fired at 1000°C, 20% sludge amended bricks fired at 950°C and 10-20% sludge amended bricks fired at 900°C satisfy the requirements of Grade-A category bricks. However, all of the prepared brick have minimum strength requirement as per BDS standard. They concluded that the compressive strength was increased at higher temperature due to the decrease in porosity and increase in density.

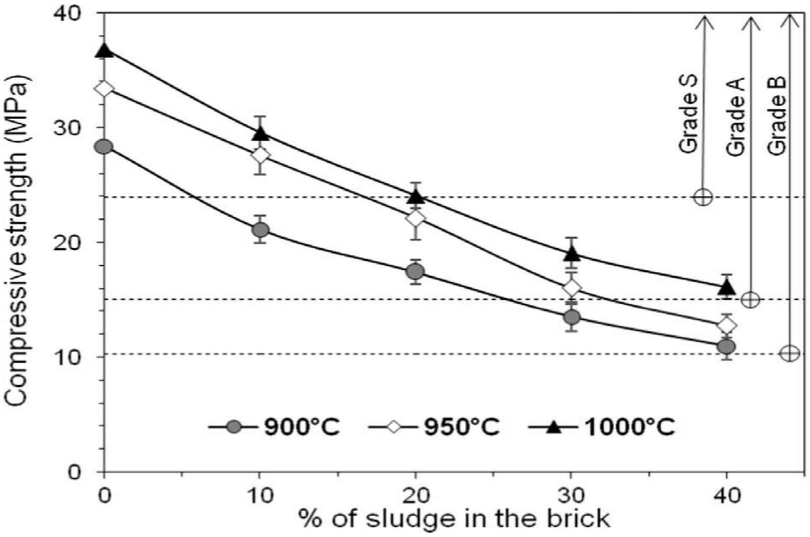

Fig. 2.7: Effect of Sludge Content and Firing Temperature on Compressive Strength of Bricks. (Juel et al. 2017)

Joo-Hwa Tay (1987) investigated the effect of replacement of clay with sludge on compressive strength of bricks. The compressive strength was determined as per BS 3921-74. Two series of samples were prepared one was prepared from oven dried sludge at 105°C for 24 hrs, another sample was prepared with sludge fired furnace at temperature of 600°C. The results of the compressive strength test of the bricks are presented in Figure 2.8. At higher temperature organic matters get removed. They reported that the compressive strength for brick sample with 10% sludge ash is similar to control sample but the compressive strength of oven dried sludge brick decreased by 30%. Similarly the compressive strength of sludge ash brick decreased by 20% for 50% replacement but for dried sludge brick the compressive strength decreases to 56% for 40% replacement.

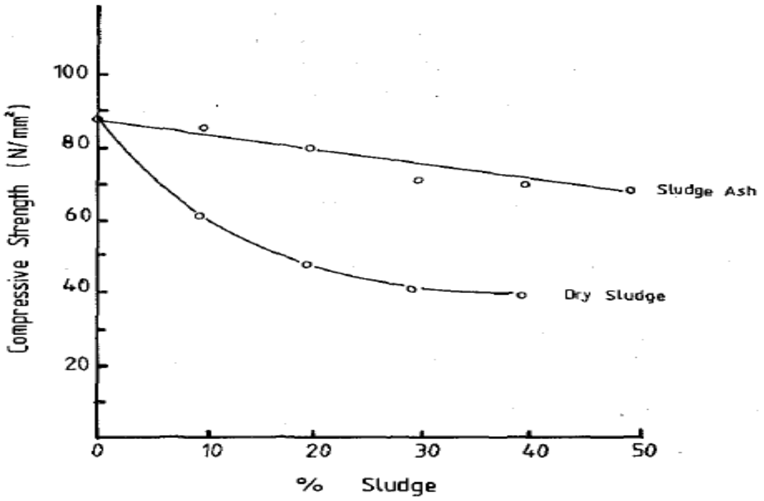

Fig. 2.8: Compressive Strength of Bricks Containing Dry Sludge and Sludge Ash. (Tay 1987)

2.3.2 Water absorption

Water absorption test is important factor for determining the durability of brick. The more water infiltrate into the brick the lesser is durability of brick. The internal structure of brick must be strong enough to avoid penetration of water.

Weng et al. (2003) investigated the water absorption of brick replacing clay with textile sludge as substitution percentage of 10, 20, 30 and 40% respectively. The water absorption was determined as per CNS 1999. The water absorption for the bricks presented in Figure 2.9. They reported that when there is replacement of clay with up to 15% sludge at a firing temperature of 960^{o}C or higher the percentage of water absorption was less than 15% which meets the requirement of first class brick. When the clay is replaced by 30% sludge and brick prepared at firing temperature of 1000^{o}C have water absorption below 20% which satisfies the category of second class brick. When firing temperature is decreased the water absorption is increased. They concluded when there is increase in replacement of clay with sludge the adhesiveness of mixture decreases, which causes the increased internal pore size of brick results increase in water absorption.

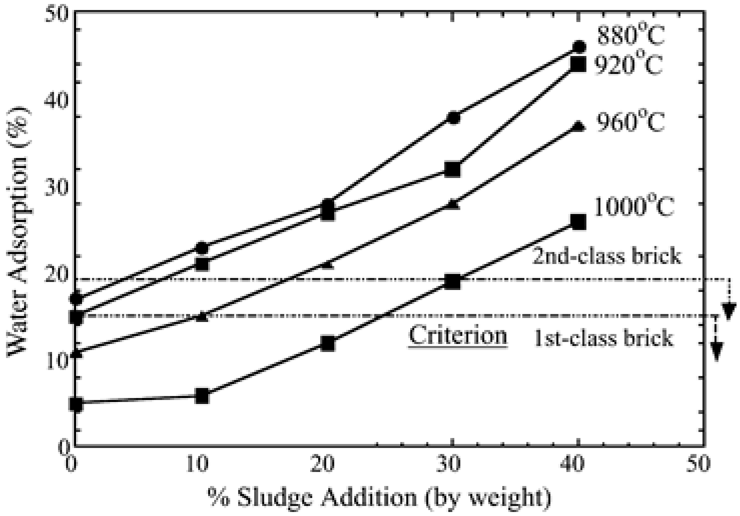

Fig.2.9: The Water Absorption of Bricks. (Weng et al. 2003)

Bhaskar et al. (2006) investigated the effect of replacement of clay with textile sludge on water absorption of brick at a replacement level of 3 to 30% with an increment of 3%. The water absorption was determined as per IS 3495 (Part II):1992. The water absorption for the bricks is presented in Figure 2.10. They reported that upto 9% replacement of clay by textile sludge have water absorption below 15%. When there is replacement of clay by 18% sludge the water absorption increases to 20%, beyond 18% replacement the water absorption increases which doesnot satisfy norms. They concluded that firing temperature results in decrease of water absorption which increases the weathering resistance of brick.

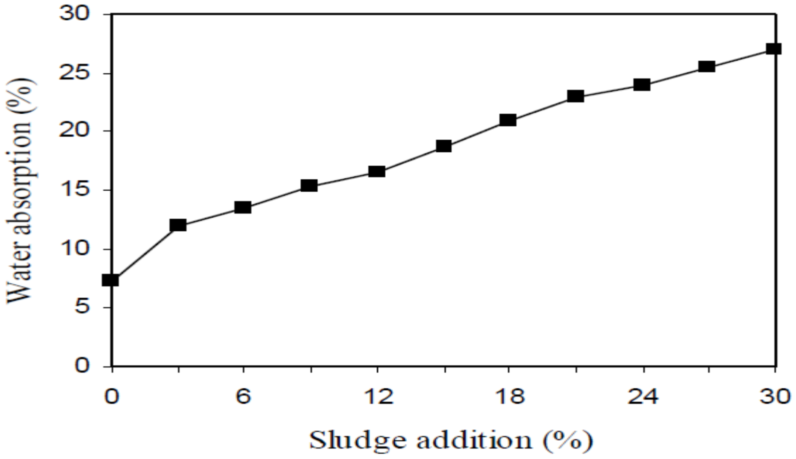

Fig. 2.10: Effect of Sludge Addition on % Water Absorption of Bricks (fired at 800ºC for 8 hours). (Bhaskar et al. 2006)

Begum et al. (2006) investigated the water absorption of brick replacing clay with textile sludge at a substitution of 3, 6, 9, 15, 20, 30 and 50% respectively at a curing age of 1 day, 7 days. The water absorption was determined as per IS 3495 (Part II): 1992. The percentage of water absorbed for bricks with variable proportions of sludge are presented in Figure 2.11. They observed that when the clay is replaced by 15% textile sludge the water absorption was less than 15% and meets the requirement of first class brick. When there is replacement of clay with 20% and 30% sludge. The brick meets the requirements of second class brick. They concluded that the water absorption of brick increases with increase in sludge addition. When there is higher replacement of sludge the adhesiveness of mixture decreases and pore size increase which results increase in water absorption.

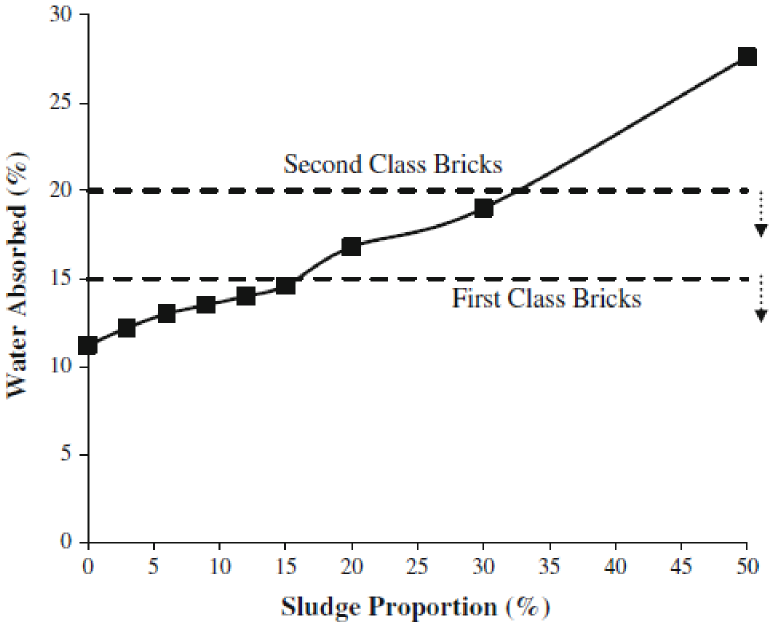

Fig. 2.11: Water Absorption of Brick. (Begum et al. 2013)

Juel et al. (2017) investigated the effect of replacement of clay with sludge obtained from leather industry on water absorption of brick at a replacement level of 10, 20, 30 and 40% respectively. The water absorption was determined as per BDS 208:2009. The results of the water absorption test as function of sludge content and firing temperature is presented in Figure 2.12. They observed that the water absorption increases with increase in sludge addition with respect to reference brick. The water absorption of 10% sludge amended brick at firing temperature of 1000°C have water absorption below 10% which meets the requirement of brick used for breaking into aggregate for plain and reinforced concrete pavement. When the clay is replaced by 20-30% of textile sludge fired at 1000°C and 10-20% sludge fired at 900°C satisfy the requirements of Grade-A category having water absorption below 15%. They concluded that when sludge particle is subjected to a higher temperature there is formation of amorphous phase at high firing temperature. Thus water absorption was reduced at higher temperature. Also sludge contains higher amounts of organic content which produces more pore spaces within the brick which causes increase in water absorption.

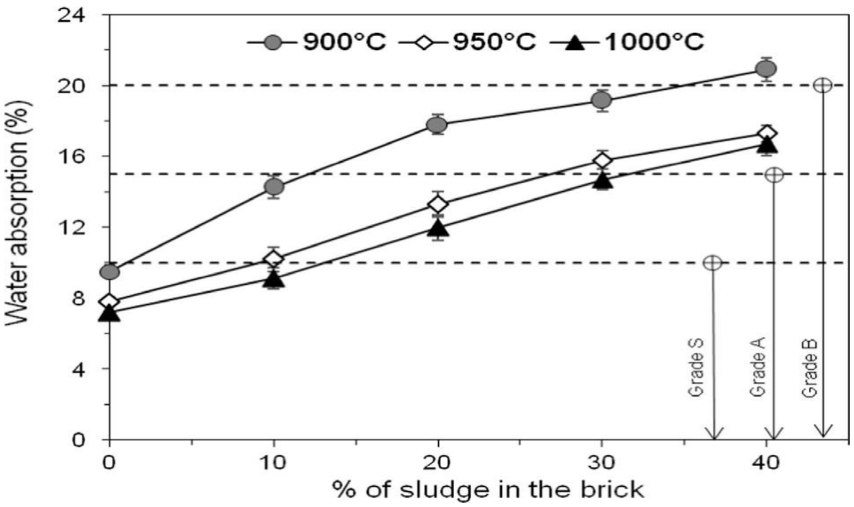

Fig.2.12: Water Absorption of Bricks as Function of Sludge Content and Firing Temperature. (Juel et al. 2017)

Joo-Hwa Tay (1987) investigated the effect of replacement of clay with sludge on water absorption of bricks. The water absorption was determined as per B.S. 3921-74. Two series of sample were prepared one was prepared from oven dried sludge at 105°C for 24 hours, another sample was prepared with sludge fired furnace at temperature of 600°C. They reported that the water absorption of reference brick was 0.03% and increases to 3.63%, for clay replaced with 40% dried sludge, but the water absorption for bricks with sludge ash increases at lower level of 1.70% for 50% sludge ash. They concluded that brick made with sludge ash have better durability than brick made with dried sludge.

2.3.3 Firing Shrinkage

Firing shrinkage in brick occurs due to chemically and mechanically bound water lost during firing process. The higher shrinkage is undesirable in engineering material. The quality of brick is further assured according to degree of firing shrinkage. Normally good qualities of bricks have shrinkage below 8%.

Weng et al. (2003) investigated the firing shrinkage of brick replacing clay with textile sludge as substitution percentage of 10, 20, 30 and 40% respectively. The results of the firing shrinkage test of the bricks are presented in Figure 2.13. They observed that the shrinkage increases with increase in replacement of clay with sludge. The firing temperature is also important parameter for determining the firing shrinkage. The increase in temperature results increase in firing shrinkage. When bricks were subjected to a temperature of 960°C upto 10% replacement of clay with sludge have shrinkage limit of less than 8%. They concluded that swelling ability, organic content of sludge causes increase in firing shrinkage.

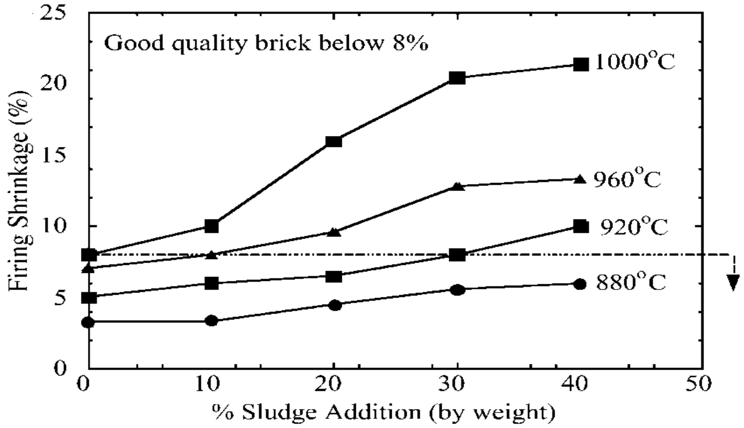

Fig. 2.13: The Brick Firing Shrinkage. (Weng et al. 2003)

Bhaskar et al. (2006) investigated the effect of replacement of clay with textile sludge on firing shrinkage of brick at a replacement level of 3% to 30% with an increment of 3%. They observed that upto 9% replacement of clay with sludge and brick fired at temperature of 800°C there is shrinkage below 0.67%. At higher replacement level the shrinkage increase for the 30% replacement of clay with sludge have maximum shrinkage of 3.4% which meets the shrinkage requirement below 8% in bricks. They concluded that the swelling ability of sludge is much higher than that of clay which cause increase in shrinkage.

Juel et al. (2017) investigated the effect of replacement of clay with sludge obtained from leather industry on firing shrinkage of brick at a replacement level of 10, 20, 30 and 40% respectively. The results of the firing shrinkage test of the bricks are presented in Figure 2.14. They reported that the firing shrinkage was decreased with the increase of sludge content. The shrinkage of brick increases with increase in the firing temperature. When the brick is subjected to firing temperature of 1000°C the shrinkage for reference brick was found to be 13% but as the replacement of clay with sludge increase i.e. at 40% replacement the shrinkage was found to be 5%. For 40%replacement at 1000°C of firing temperature shrinkage reduces by 50.8% compared to reference brick. Similar observations were made for 900°C and 950°C. They concluded that there is decrease in shrinkage with increase in substitution percentage due to then increase in non plastic nature of dried sludge. The low plastic soil shrinks less than high plastic soil. The decreasing trend might be due to expansion of brick during firing process. Sludge amended brick could release more gases during firing as compared to the reference brick due to the burning of organic matter present in it and these gases could not get removed out from clay matrix during firing due to lack of connectivity among pores spaces. This process generates voids which may cause net expansion within clay-sludge matrix results in lower net shrinkage.

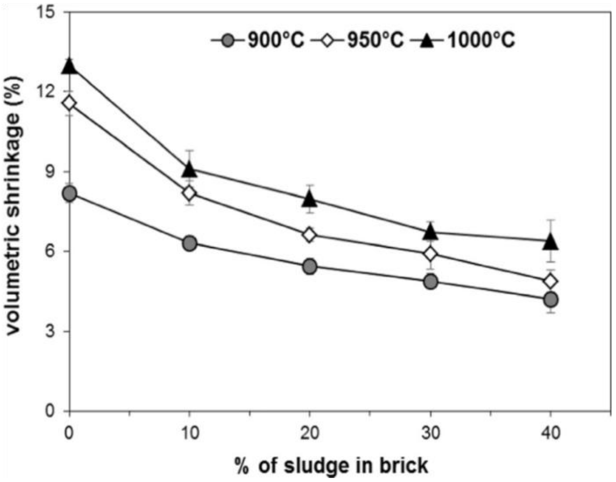

Fig. 2.14: Shrinkage of Bricks as Function of Firing Temperature and Sludge Content. (Juel et al. 2017)

2.3.4 Weight Loss on Ignition

Weng et al. (2003) investigated the weight loss on ignition of brick replacing clay with textile sludge as substitution percentage of 10, 20, 30 and 40 respectively. The results of the of weight loss on ignition of the bricks are shown in Figure 2.15. They observed that for the firing temperature of 1000⁰C, 960⁰C, 920⁰C and 880⁰C showed the clay replaced by 10% sludge have loss of ignition below 15% which satisfies the requirement of first class brick as per Chinese Nation Standard. They concluded that the weight loss on ignition for a clay brick subjected to a firing temperature above 800⁰C is dependent on the organic matter present. The sludge addition in the mixture causes loss in weight due to presence of organic and inorganic substance burnt off during firing process.

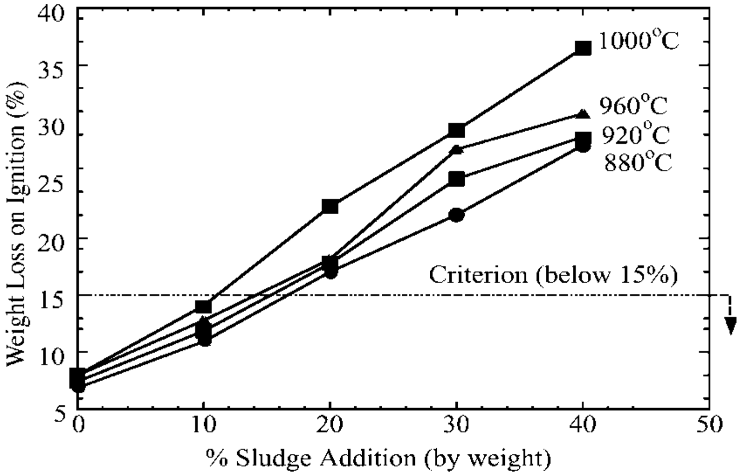

Fig.2.15: The Weight Loss on Ignition of Bricks. (Weng et al. 2003)

Bhaskar et al. (2006) investigated the effect of replacement of clay with textile sludge on weight loss on ignition of brick at a replacement level of 3 to 30% with an increment of 3%. When the brick is subjected to a firing temperature of 800⁰C for 8 hours the weight loss on ignition for reference brick was 3.41% and increases with replacement of 30% was 9.51%, which was less than 15% satisfy the requirement for weight loss on ignition of brick. They concluded that as the firing temperature increases weight loss on ignition increases. The weight loss on increase in sludge replacement due to organic content, inorganic substance burnt off during firing.

Begum et al. (2013) investigated the weight loss on ignition of brick replacing clay with textile sludge at a substitution of 3, 6, 9, 15, 20, 30 and 50% respectively at a curing age of 1 day, 7 days. The results of the of weight loss on ignition of the bricks are presented in Figure 2.16. They observed that reference brick have loss of ignition of 1.8% whereas for 50% sludge amended brick the loss of ignition was 11.8%. All the bricks manufactured satisfy the requirement of loss of ignition below 15%. They concluded that for control brick the weight loss on ignition is mainly due to organic component burnt off during firing. Moreover for sludge-clay bricks it depends on the organic and inorganic substance being burnt during firing.

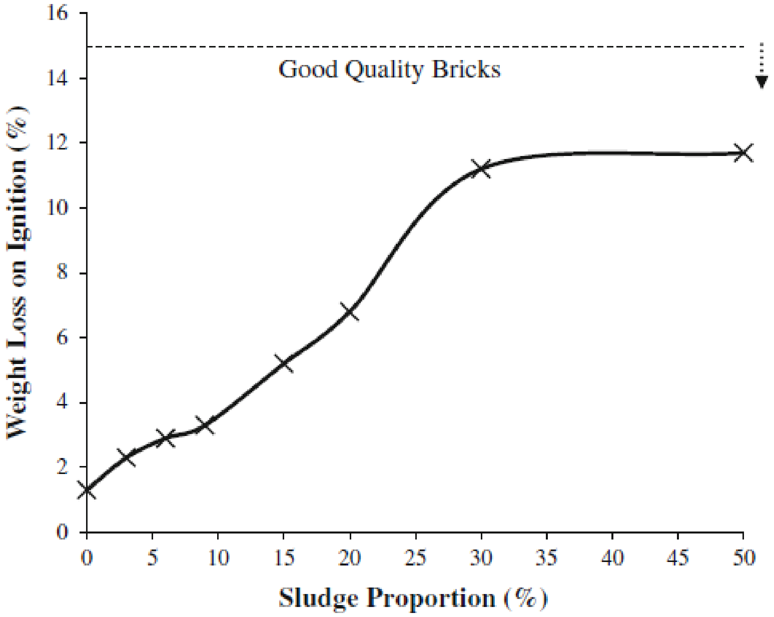

Fig. 2.16: Weight Loss on Ignition of Brick. (Begum et al. 2013)

Juel et al. (2017) investigated the effect of replacement of clay with sludge obtained from leather industry on water absorption of brick at a replacement level of 10%, 20%, 30% and 40% respectively. The results of the of weight loss on ignition of the bricks are presented in Figure 2.17. They observed that loss on ignition for reference brick at 900°C was 5.52% and for 850°C and 1000°C was 6.5% and 7.5% respectively. With the increase in temperature the 40% sludge amended brick have highest loss on ignition of 16.5%. They reported that the weight loss on ignition increases with increase in percentage of sludge replacement. The weight loss on ignition also depends upon the firing temperature as firing temperature increases the weight loss on ignition increases. They concluded that the loss on weight is due to burning and decomposition of organic and in organic matter present in sludge and clay.

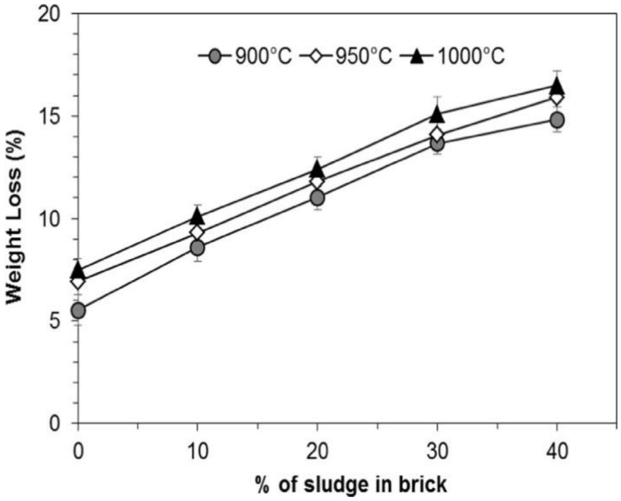

Fig.2.17: Weight Loss of Bricks as Function of Sludge Content and Firing Temperature. (Juel et al. 2017)

2.3.5 Bulk density

Weng et al. (2003) investigated the bulk density of brick replacing clay with textile sludge as substitution percentage of 10, 20, 30 and 40 respectively. The results of the bulk density of the bricks are presented in Figure 2.18. They observed that the bulk density was decreased with increase in sludge addition. For control brick the density was 2gm/cm^3 reduces to 1.3gm/cm^3 for 40% sludge amended brick. Similarly when firing temperature was 960°C the density of control brick was 1.9gm/cm^3 and for 40% sludge amended brick was 1.2gm/cm^3. They concluded that when there is increase in replacement of clay with sludge the mixture absorbs more water, which causes increase in pore size results in lighter density. Also at high firing temperature the particle density increases.

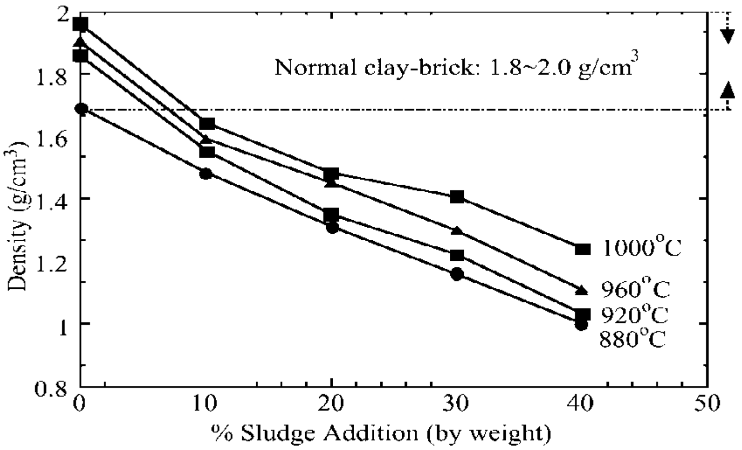

Fig. 2.18: The Particle Density of Bricks. (Weng et al. 2003)

Juel et al. (2017) investigated the effect of replacement of clay with sludge obtained from leather industry on bulk density of brick at a replacement level of 10, 20, 30 and 40% respectively. The results of the bulk density of the bricks are presented in Figure 2.19. They observed that the bulk density decreased from 1872 kg/m^3 to1505 kg/m^3, when sludge content is increased from 0% to 40% at 1000°C of firing temperature. Similar trends were observed at 950°C and 900°C. They conclude that there was slight increase in bulk density at higher temperature.

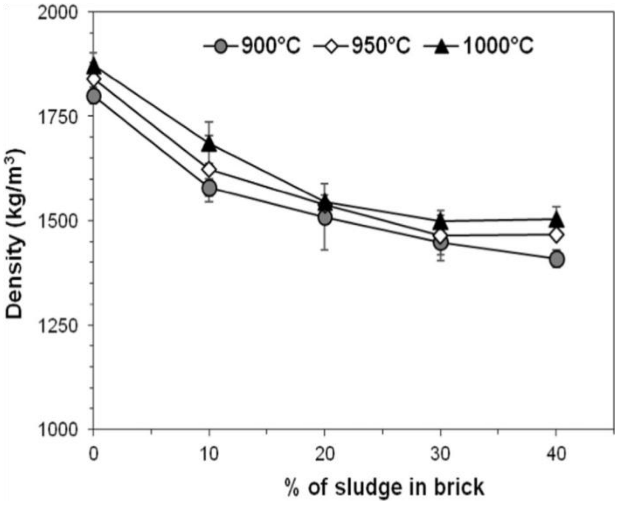

Fig. 2.19: Bulk Density of Bricks as Function of Firing Temperature and Sludge Content. (Juel et al. 2017)

Begum et al. (2013) investigated the bulk density of brick replacing clay with textile sludge at a substitution of 3, 6, 9, 15, 20, 30 and 50% respectively at a curing age of 1 day, 7 days. They observed that all the bricks subjected to a firing temperature of 1000ºC have density above 1.8gm/cm^3 which satisfy the requirement of bulk density of brick 1.8-2.5gm/cm^3. For the reference brick the bulk density were 2.25gm/cm^3 and for 50% replacement have bulk density of 1.9 gm/cm^3 upto 9% replacement of clay with sludge have density nearer to the control brick. They concluded that the brick absorbed more water which causes increase in pore size resulting decrease in density.

CHAPTER 3

EXPERIMENTAL PROGRAM AND METHODOLOGY

3.1 General

The basic objective of the research is to investigate the partial replacement of cement with textile sludge on cement sand mortar. This chapter includes detail of various raw materials used for making mortar and their physical properties. It also includes mix proportions of raw materials to make mortar mixes. This chapter also includes the details of test procedure adopted to find out fresh properties, hardened properties i.e. compressive strength and tensile strength and durability properties i.e. water absorption, rapid chloride permeability, sorptivity and shrinkage.

3.2 Properties of Constituent Material

Different raw materials include cement, textile sludge, standard sand and water. Test of raw materials were conducted as per Bureau of Indian Standard specification.

3.2.1 Cement

Ordinary Portland Cement (OPC), Grade 43, Ultra Tech was used in the study. It was greyish in colour and was free from any lumps. The test results are given in Table 3.1.

Table 3.1: Properties of Ordinary Portland Cement

Property	Test Result			Test Procedure as per Code
Fineness (% retained on 90 micron sieve)	2.5%			BIS 4031(Part 1):1996
Soundness (mm)	1			BIS 4031(Part 3):1988
Standard consistency (%)	28.5			BIS 4031(Part 4):1988
Initial setting time (mins)	120			BIS 4031(Part 5):1988
Final setting time (mins)	237			
Compressive strength (MPa)	3 days	7 days	28 days	BIS 4031 (Part 6):1988
	26.3	36.08	45.56	

3.2.2 Textile Sludge

Textile sludge used in this work was obtained from a local textile industry and it was brown in colour. The sludge was oven dried at a temperature of 100±5˚C for 5 days to remove the moisture. Textile sludge was weighted at regular intervals so as to record the loss of moisture from it. It was dried until we got a constant mass. It was observed that a constant mass of textile sludge sample was obtained after drying for 5 days. After oven drying the sample was made powered form in a grinder. Some of the images of the textile sludge and the processed textile sludge are shown in Figure 3.1.

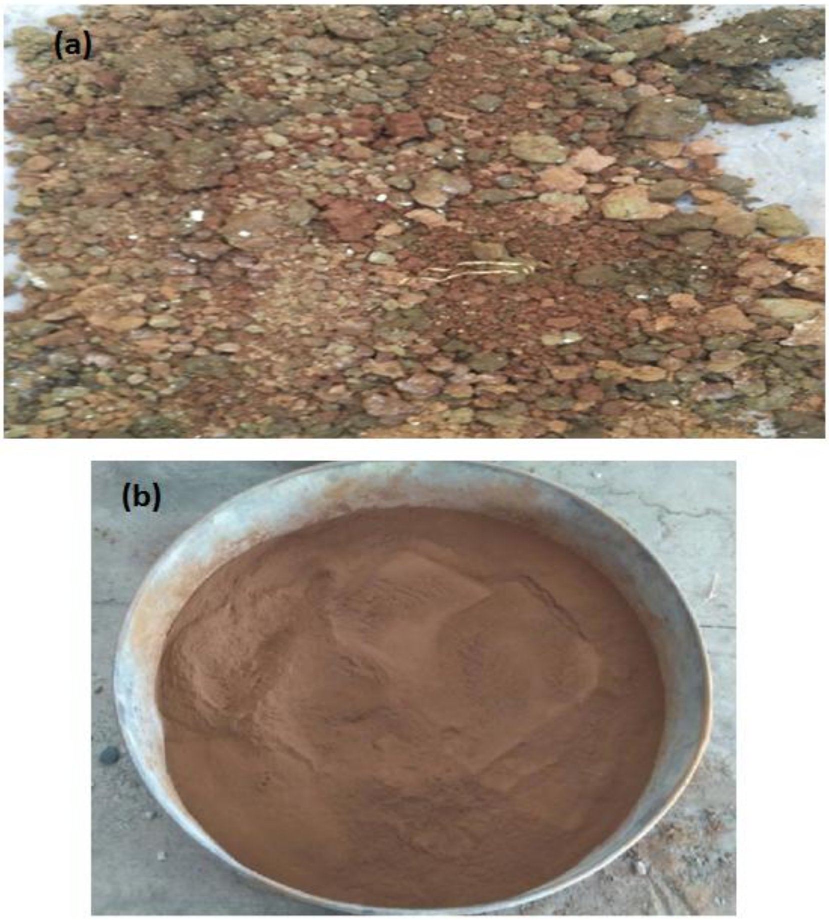

Fig. 3.1: (a) Raw Textile Sludge; (b) Processed Textile Sludge.

Physical properties of textile sludge are given in Table 3.2. The specific gravity was measured by density bottle method as per BIS 4031(Part 11):1988. The fineness of textile sludge was found out by dry sieving through 90 micron sieve as per BIS 4031 (Part 1) 1996.

Table 3.2: Physical Properties of Textile Sludge

Property	**Observed Values**
Colour	Brown
Specific gravity	2.32
Fineness (% retained on 90 micron sieve)	1

Chemical properties of textile sludge are given in Table 3.3. Oxide composition of textile sludge sample was determined using AAA spectroscopy.

Table 3.3: Chemical Composition of Textile Sludge

Chemical Composition	**Test Method**	**Results (%)**
CaO	IS: 1727-1967, Reaffirmed-2004 & AAS	33.5
SiO_2	IS: 1727-1967, Reaffirmed-2004	3.8
Al_2O_3	IS: 1727-1967, Reaffirmed-2004 & AAS	0.3
Fe_2O_3	IS: 1727-1967, Reaffirmed-2004 & AAS	18.9
SO_3	IS: 1727-1967, Reaffirmed-2004	0.40
MgO	IS: 1727-1967, Reaffirmed-2004 & AAS	1.0
Na_2O	Digestion followed by flame photometer	0.06
K_2O	Digestion followed by flame photometer	0.04
Loss on ignition	IS: 1727-1967, Reaffirmed-2004	40.6

X-ray diffractogram of textile sludge is shown in Figure 3.2. Analysis of diffractogram peaks shows that textile sludge mainly contains calcite.

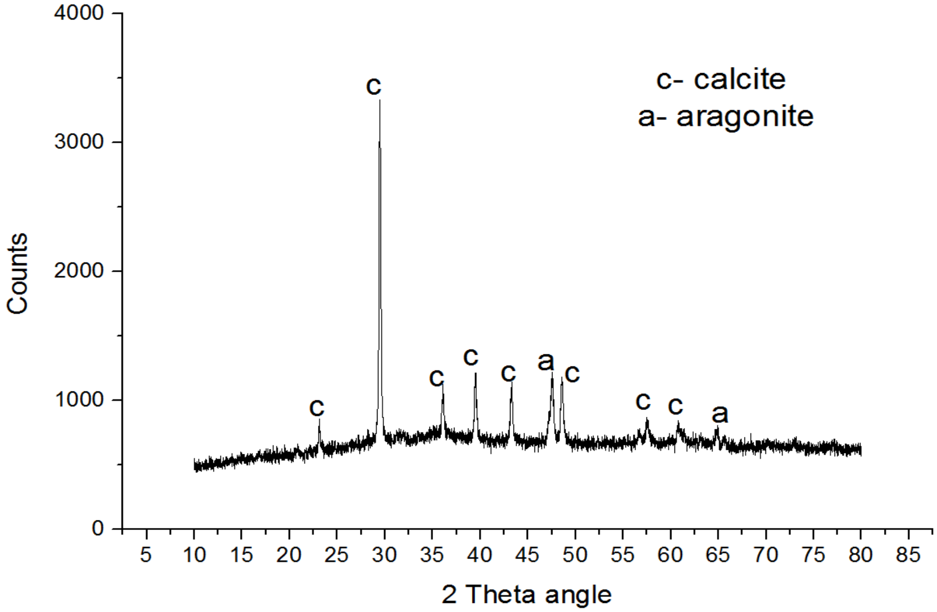

Fig.3.2: X-ray Diffraction of Textile Sludge

3.2.3 Sand

Indian standard sand was used throughout the research work. Particle size distribution of standard sand was such that it retained 100% on 90 micron sieve BIS sieve. It is divided into proportions known as grade I, grade II and grade III respectively. Details about particle size distribution of grade I, grade II and grade III standard sand is given in Table 3.4. All these specifications were found to be as per requirement given by BIS: 650-1991.

Table 3.4: Particle Size Distribution

Type of Grade	Particle Size
Grade I	Particle size smaller than 2mm and greater than 1mm
Grade II	Particle size smaller than 1mm and greater than 500 microns
Grade III	Particle size smaller than 500 micron and greater than 90 microns

3.2.4 Water

Portable water was used for preparing cement mortar sample. The water was added as per the consistency obtained. Water added = $\left(\frac{P}{4}+3\right)$ % of total mass of binder and sand where P = water percentage requirement to produce a paste of standard consistency.

3.3 Sample Preparation

Mortar sample was prepared according to BIS 4031 (Part 6):1988 provision with binder to sand ratio 1:3. The replacement percentages were varied from 5% to 20% with an increase of 5% for each mix. Samples for each mixes with variable percentage of textile sludge were casted. Table 3.5, 3.6 and 3.7 gives the mix proportioning and corresponding nomenclature of ingredients for the preparation of different test specimens. The control mix is designated as CM and the mixes containing textile sludge of 5, 10, 15 and 20% are designated as TS5, TS10, TS15 and TS20, respectively.

Table 3.5: Mix Proportion of Cubes (70.6mmx70.6mmx70.6mm)

Mix Designation	Weight of Cement (gms)	Weight of Textile Sludge (gms)	Wt. of I.S Sand TypeI, TypeII, TypeIII (gms) each	Water (gms)
CM	200	0	200	81
TS5	190	10	200	82
TS10	180	20	200	83
TS15	170	30	200	84
TS20	160	40	200	85

Table 3.6: Mix Proportion of Cylinder (100mmx200mm)

Mix Designation	Wt. of Cement (gm)	Wt. of Textile Sludge (gm)	Wt. of I.S Sand TypeI, TypeII, TypeIII (gm) each	Water (gm)
CM	1000	0	1000	405
TS5	950	50	1000	410
TS10	900	100	1000	415
TS15	850	150	1000	420
TS20	800	200	1000	425

Table 3.7: Mix Proportion of Prism (300mmx25mmx25mm)

Mix Designation	Wt. of Cement (gm)	Wt. of Textile Sludge (gm)	Wt. of I.S Sand TypeI, TypeII, TypeIII (gm) each	Water (gm)
CM	400	0	400	162
TS5	380	20	400	164
TS10	360	40	400	166
TS15	340	60	400	168
TS20	320	80	400	170

3.4 Details of Test Specimen

The details of samples prepared to conduct different tests are given in Table 3.8.

Table 3.8: Specimen Details for Tests

Test Conducted	Specification (mm)	Specimen
Compressive and split tensile strength	70.6x70.6x70.6	Mortar cubes
Water absorption	70.6x70.6x70.6	Mortar cubes
Rapid chloride-ion permeability test, sorptivity	100x200	Mortar cylinder
Shrinkage	300x25x25	Prism
XRD	Passing through 90 micron sieve	Powdered sample after 28 days of testing
SEM	10x10x10	Small piece of tested mortar cubes

3.5 Experimental Program

This section includes the methodology and test procedure used for evaluation of fresh properties (consistency, initial, final setting time and soundness, workability), hardened properties (compressive strength and split tensile strength) and durability properties (water absorption, rapid chloride penetration test, sorptivity and drying shrinkage) and mineralogical and micro structural characteristics (XRD and SEM). The experimental program and test matrix is presented in Figure 3.3.

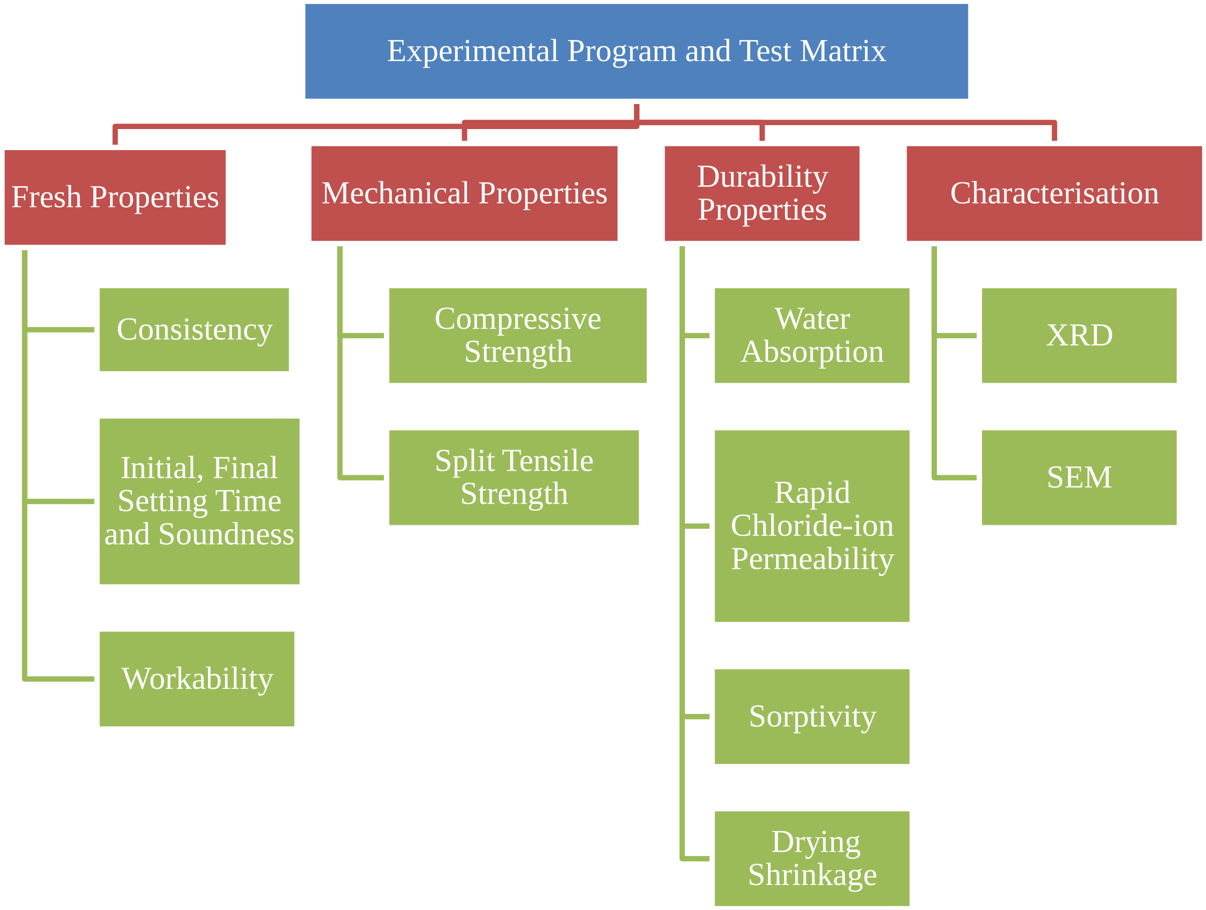

Fig. 3.3: Experimental Program and Test Matrix

3.6 Casting and Curing

All concrete specimens were casted in cast iron moulds which were tightened and lubricated properly. For the casting compaction was done with vibrating table. For preparation of mortar mixes hand mixing was done. Firstly all ingredients i.e. cement, cement/sludge, standard sand and water were weighted with an accuracy of 0.5 gm. All ingredients except water were dry mixed properly before adding water. After addition of water, hand mixing with the help of trowel was done until the mortar converts into uniform mass. After compaction all specimens were left in casting room for 24 hours. After completion of 24 hours specimens were demoulded and carefully put into curing tank at a temperature of 27 ± 2^{0}C till testing age. For each mix 24 cubes (70.6mmx70.6mmx70.6mm), 9 for compressive strength for 3, 7, 28 days, 9 for split tensile strength at 7, 14, 28 days and 6 for water absorption at 7, 28 days were casted. For the evaluation of rapid chloride penetration test and sorptivity 2 cylindrical specimens of size 100mmx200mm were casted for each mortar mixes. For the evaluation of shrinkage 3 prism specimens of size 300mmx25x25mm were casted for each mortar mixes.

3.7 Tests Conducted

This section describes various test conducted on cement sludge mortar to evaluate different fresh hardened, durability property and mineralogical and microstructure characteristics.

3.7.1 Fresh Mortar Tests

The fresh properties of mortars are:

- Consistency
- Initial and final setting time
- Soundness
- Workability

3.7.1.1 *Standard Consistency*

Standard consistency of binder can be described as the percentage of water by weight of binder which produces a standard consistency that permits a plunger of 10mm diameter to penetrate upto a depth of 5mm to 7mm above the bottom of vicat's mould. The test was conducted as per BIS 4031(Part 4):1988. Vicat's apparatus fitted with 10mm diameter was used to perform a standard consistency test.

400gm of binder i.e. cement/textile sludge was taken and placed on an enamel tray. The indicator of vicat's mould was adjusted so that it shows zero reading. About 25% of clean water by weight of binder was measured. The sample was mixed thoroughly. The vicat's mould was filled with prepared paste, which was placed on nonporous glass plate. The mould was shaken to remove the entrapped air. The surface was made leveled with trowel. The mould was placed under the plunger and the clamp was unscrewed to bring plunger in contact of the surface of plate and released. The penetration reading from bottom was noted. If reading obtained was more than 5 to 7mm from bottom, water content was increased. If reading obtained was less than 5 to 7mm from bottom, water content was reduced. The vicat's apparatus used for determining standard consistency of cement/textile sludge paste is shown in Figure 3.4.

Fig. 3.4: Standard Consistency of Cement/Textile Sludge Paste with Vicat Apparatus

3.7.1.2 *Initial and Final Setting Time*

The phenomenon of setting denotes the reaction between binder and water, and loss of plasticity of binder paste. Initial setting time of cement is defined as the time period elapsed between the time when water was added to binder and the time at which needle of 1mm diameter fails to pierce the test block to a depth 5-7mm from bottom of mould. The test was conducted as per BIS 4031(Part 5):1988.

400 gm of binder was taken and placed on enamel tray. Water was measured 0.85p times the weight of binder. Before making cement paste, 1mm diameter needle was fitted on vicat's apparatus. The needle upto zero mark was adjusted when the needle just touches the bottom of

non porous plate. Mix the measured quantity of water in binder and simultaneously initial time on stopwatch was started. The vicat's mould was filled and the surface was leveled. The prepared mould was placed under the needle. The needle was lowered till it comes in contact with the surface of mould and gently released and allowing it to penetrate into mould. The experiment was repeated till needle fails to pierce mould 5 to 7mm.

To determine the final setting time, the needle used for determining initial setting time was replaced by another needle which had annular attachment. This needle with annular attachment is touched gently with the test block to see impression of needle as well as annular attachment. The cement paste is to be considered to be finally set at the moment when there will be impression of needle only where as annular attachment was unable to make an impression. The vicat's apparatus used for determining setting time of cement/textile sludge paste is shown in Figure 3.5.

Fig. 3.5: Setting Time of Cement/Textile Sludge Paste with Vicat Apparatus

3.7.1.3 *Soundness*

One of the most important properties of binder is its soundness. The cement is considered Unsound when there is undue expansion of some of the constituents like free lime produced in the manufacturing process of cement. Another possible cause of unsoundness is the presence of too high amount of magnesia content in the cement. The test was conducted as per BIS 4031(Part 3):1988**.**

The binder paste was prepared by adding 0.78 times the water required, to produce a standard consistency. The Lechatelier's mould was oiled and placed on glass plate. The mould was filled with the binder paste. The mould was covered with another piece of lightly oiled glass sheet and small weight was placed on glass sheet. The whole assembly was kept under water at a temperature of 27 ± 20°C and kept for 24 hours. The whole assembly was removed from the water bath and the distance between indicators was measured. After that the specimens were submerged in the boiling water for 3 hours. The mould was removed from water and allowed for cooling and distance L_2 between indicators was measured. The change in distance measurement gives expansion of binder.

3.7.1.4 *Workability*

Marsh cone test is done to study fresh property of cement paste and binder paste. Marsh cone is used to measure the viscosity by observing the time that it takes to a known volume of liquid to flow from a cone. The test was performed as per ASTM C 939-2002. The apparatus required are mortar mixer, graduated cylinder, trowels, stop watch, conical vessel having orifice of 8mm diameter at bottom.

The cement sample, cement and textile sludge sample was taken in standard mortar mixture. The mixture was dry mixed at a speed of 140±5 rpm for 1min. Two third of water was added for one and a half minute at slow speed of rotation. The mixing was stopped and paste was collected from sides of mortar mixture. The mortar mixture was mixed again at a rotation speed of 285±10rpm for two minutes. The mix prepared was filled to the marsh cone test attached to the stand. A graduated cylinder was placed under the orifice of the marsh cone. The orifice was closed while filling the marsh cone and 1000ml of the mix was filled into the marsh cone. While pouring the mix the entrapped air should be minimized. The stop watch was started as the orifice was opened. The time required for the flow of 900ml of cement and cement sludge mixture was noted. The time noted is the flow time of mix. The standard mortar mixture and marsh cone apparatus used for determining fluidity of cement/textile sludge is shown in Figure 3.6.

Fig.3.6: (a) Mortar Mixture; (b) Marsh Cone Apparatus to Test Flow Time

3.7.2 Hardened Concrete Tests

The properties of hardened concrete are those concerned to strength which are of practical importance.

3.7.2.1 Compressive Strength

The compressive strength of cement binder mortar was calculated as per the procedure given in BIS 4031 (Part 6): 1988. Cubical specimens of dimensions 70.6mm x 70.6mm x 70.6mm were casted with 1:3 cement sand mortar, using standard sand as per specification given in BIS 650-1991. After casting, the specimens were demoulded after 24 hours and properly cured. The compressive strength of cubical specimens were tested for 3,7 and 28 days. Compressive strength was tested on automatic compression testing machine (ACTM) having capacity 5000 kN. At the time of testing rate of load was maintained at 70 kN/min. The apparatus set-up for compressive strength is shown in Figure 3.7.

Fig. 3.7: Automatic Compression Testing Machine for Compressive Strength Test

3.7.2.2 Split Tensile Strength

It is known as indirect test for measuring the tensile strength of concrete. The split tensile property is necessary because mortars are subjected to tensile cracking due to method of load application. However, tensile strength of mortar paste is very low as compared to compressive strength. The test was performed as per BIS 5816:1999. Cubical specimens of dimensions 70.6mm x 70.6mm x 70.6mm were casted with 1:3 cement sand mortar. After casting the specimens were demoulded after 24 hours and properly cured. The split tensile strength of cubical specimens were tested for 7, 14 and 28 days. Before keeping the cement binder mortar cubes on the testing machine the surfaces of testing machine and load strip was cleaned the specimens were placed exactly in the centre. The mortar specimens were placed at an angle of 45 degree the axes of the specimens to be tested was carefully placed with the center of lower pressure plate of testing machine. The split tensile strength was tested on automatic compression testing machine (ACTM) having capacity 5000 KN. At the time of testing load was applied at 70kN/min. The apparatus set-up for split tensile strength is shown in Figure 3.8.

Fig. 3.8: Automatic Compression Testing Machine for Split Tensile Strength Test

3.7.3 Durability Tests

The durability of mortar can be defined as its ability to perform satisfactory under environmental exposures condition and weathering actions. The durability property mainly depends upon the surface characteristics of mortar. Various tests were conducted to know durability property of mortar.

3.7.3.1 Water Absorption

The water absorption test study on mortars gives amount of total pore volume present in the mortars sample. The pore structure of mortar plays an important role in durability of mortar. The test was performed as per ASTM C 642-2013.Water absorption test was conducted on cube specimens having dimensions 70.6×70.6×70.6 mm. After casting the cubes, they were first put into curing tank and taken out at specified period of testing. They were then oven dried for 24 hours at a temperature of 110°C. The dry weight of the specimens was noted after cooling it to the room temperature and then they were immediately immersed in water for duration of 96 hours. After that, the specimens were taken out and the surplus water was wiped with a soft cloth and then their saturated weight was noted down. Tests were done at 7 days after initial curing of 28 days and 28 days after initial curing of 28 days respectively. Water absorption of mortar is equal to ratio of difference between the mass of saturated sample to mass of oven dried sample expressed in percentage.

3.7.3.2 Rapid Chloride-ion Permeability

This test method is used to determine the electrical conductance of concrete and mortar. It provides a rapid indication of resistance to chloride-ion. The test was performed as per ASTM C 1202-2010. Rapid chloride-ion permeability test apparatus, vacuum desiccators, vacuum pump, and sealants were used to perform the test. The cylindrical mortar specimens 100mm in diameter 50mm in height were used in testing. Three specimens were made for testing for each mix at the selected age. Before start of the test specimens were vacuum saturated for 3 hours by placing in desiccators. After vacuum saturation the specimens were taken out and placed in an apparatus with 3% NaCl solution in one side and 0.3N NaOH solution in other side. A constant voltage of 60V was applied between anode and cathode. Rapid chloride-ion penetration resistance of test specimens were calculated in terms of charge passed in coulombs after 6 hours. Tests were done after 28 days after initial curing respectively. The rapid chloride-ion permeability test set-up is shown in Figure 3.9.

Fig. 3.9: Rapid Chloride Permeability Test Set-up.

The rapid chloride-ion permeability test however, does not directly measure the depth or rate of chloride penetration. For quality control and acceptance testing applications, (ASTM C 1202-2010) recommends the use of qualitative terms rather than the numerical results of the test, both shown in Table 3.9.

Table 3.9: Chloride-ion Penetrability Based on Charge Passed

Charge passed (Coulombs)	**Chloride ion penetrability**
4000	High
2000 – 4000	Moderate
1000 – 2000	Low
100 – 1000	Very low
100	Negligible

3.7.3.3 Sorptivity

Sorptivity test method determines the rate of water absorption by measuring the increase in the mass of the mortars specimen when the surface of mortar specimen is exposed to water. The water penetrates in to the specimen by capillary action. It is based on Darcy's law of unsaturated flow. The test was performed as per ASTM C 1585-2004. The cylindrical concrete specimens 100 mm in diameter and 200 mm in height are first casted and water curing was done for 28 days then cut by a water-cooled diamond saw to get the specimens (to be tested) having 50 mm thickness and 100 mm diameter. Three specimens were prepared for each mix. A total of 15 samples were prepared. The sample was dried in the oven at 50°C for 3 days. The sides of cylinder samples were sealed with epoxy. After drying of epoxy the sides of the samples were covered by adhesive tape. The specimens were submerged to height 1 to 3 mm. The initial weights of the specimens were measured. At a time interval of 5, 10, 15, 20, 30, 60, 120 and 180 minutes the samples were removed from pan and dried with cloth and weight of the sample was taken. The increase in mass per unit area over the density of water versus the square root of time elapsed was plotted. The slope of best fitted line of these points was taken as sorptivity value for the specimens sorptivity was measured for 3 samples of each mix and average value was taken as representative sorptivity. The sorptivity test set-up of cement/textile sludge is shown in Figure 3.10.

Fig.3.10: Sorptivity Test of Cement/Textile Sludge

3.7.3.4 Drying Shrinkage

When the mortar dries after curing under the wet condition, it shrinks during the drying process. The drying shrinkage is defined as the contraction of the hardened mortar sample due to the loss of capillary water. The decrease is caused by any factor without adding any external forces, under the condition of temperature, relative humidity. This test method establishes the relation at constant temperature, relative humidity, and rate of evaporation of the environment to which a mortar specimen subjected to particular period of time during which the change in length is determined. The shrinkage causes an increase in tensile stress which may causes cracking, internal wrapping, and external deflection without application of any load. The test was performed as per ASTM C 157-2003. The prism mortar specimens 300x25x25 mm in size were casted. Three specimens were prepared for each mix. A total of 15 samples were prepared. At the age of 7 days of curing the sample were removed from water and wiped with dry cloth and immediately the initial reading was measured on length comparator. After that the sample kept in the room temperature. The reading was measured for the same sample after 7, 14, 28, 35 and 42 days respectively. The change in length of each specimen of drying shrinkage test was obtained by substracting with the initial reading. The average reading of three samples was calculated. The drying shrinkage length change of the sample was expressed in µm/m. Length comparator for measuring drying shrinkage deformation is shown in Figure 3.11.

Fig.3.11: Length Comparator to Measure Drying Shrinkage Deformation

3.7.4 Characterization Techniques

3.7.4.1 X-ray Diffraction

The basic aim of XRD analysis is to analyze various changes in cement phases due to addition of textile sludge as binder. For this small pieces of mortar were collected from core of the cubical specimens at the time of compressive strength testing at 28 days. These mortar pieces were crushed to form powder which was sieved through 90 micron sieve. The portion of the powder passing through 90 micron sieve was used for XRD test. XRD pattern was recorded with X-ray diffractogram CuKα radiation (λ=1.54Å) at diffraction angle of 2θ in range of 10^0 to 70^0 in steps of 2θ=0.013. Diffraction peaks obtained analyzed using software tool of Xpert High Score.

3.7.4.2 Scanning Election Microscopy

Scanning election microscopy is conducted to study the microstructure property of textile sludge. For this small pieces of mortar were collected from core of the cubical specimens at the time of compressive strength testing at 28 days. This test is used to identify the changes which had occurred inside the microstructure.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 General

In this chapter the results of test conducted in order to investigate the effect of addition of textile sludge on the property of cement mortar is presented. The textile sludge used as partial replacement of cement. The replacement percentages are taken as 5, 10, 15 and 20% respectively. The various fresh, hardened properties, durability properties and mineralogical and microstructure properties of mortar made by replacing cement with textile sludge are discussed and compared between the different mixed proportions. The mix proportions and test procedures are presented in chapter 3.

4.2 Effect of Addition of Textile Sludge on Fresh Properties of Mortar

To study the effect of fresh properties of mortar the textile sludge is used as partial replacement of cement. The mortar was prepared from textile sludge were tested for consistency, initial and final setting time, soundness and workability.

4.2.1 Standard Consistency

The consistency of various mortar pastes made by adding variable percentage of textile sludge is shown in the Table 4.1. It can be observed that standard consistency of cement sludge mortar paste increases with increase in percentage replacement of cement with textile sludge. Standard consistency of control mix was lowest among all mortar mixes where as standard consistency of mortar mixes with 20% textile sludge was found to be maximum.

Consistency of binder/paste is increased from 28.5 to 30.5% on using 20% of textile sludge as a partial replacement of cement. It means with the inclusion of textile sludge higher water content is needed to produce cement/sludge paste having standard consistency. Also it can be due to higher fineness of textile sludge demands more water as compared to cement. Similar observation was also reported by Balasubramanian et al. 2006, Patel and Pandey 2012, Cheiraf et al.2015.

Table 4.1: Standard Consistency of Binder Paste

Mix Designation	Cement (gms)	Sludge (gms)	Water (ml)	Standard Consistency (%)
CM	400	0	114	28.5
TS5	380	20	116	29
TS10	300	40	118	29.5
TS15	340	60	120	30
TS20	320	80	122	30.5

4.2.2 Initial, Final Setting Time and Soundness of Binder Paste

The results of initial, final setting time and soundness are shown in Table 4.2. Initial and final setting time of mixes having textile sludge increases with increase in percentage replacement of cement with textile sludge. Initial and final setting time of control mix was lowest among all mortar mixes. The Initial and final setting time with 20% textile sludge was found to be maximum.

Initial and final setting time of the control mix was 110 minutes and 235 minutes. The initial setting time of cement /sludge paste containing TS5, TS10, TS15 and TS20 is 5.45, 21.82, 40.91 and 59.09% more than the control mix. Similarly the final setting time of mixes TS5, TS10, TS15 and TS20 are 5.96, 15.32, 27.36 and 38.30% more than control mix. The increase in setting time of binder paste causes delay in hydration process. However both initial and final setting time of all the paste meets the requirement as per BIS 4031-1988 (Part 5) i.e. initial and final setting time of binder paste should be more than 30 minutes and less than 600 minutes respectively.

The increase in initial setting time makes the mortar workable for longer period of time. The differences between initial and final setting times i.e. (Δt) of various mixes remains almost close which means that if initial time has reached the setting process takes similar time for all mixes.

The cement is considered to be unsound when there is undue expansion of some of the constituents like free lime produced in the manufacturing process of cement. Another possible cause of unsoundness is the presence of too high amount of magnesia content in the cement. The expansion values of mortars are almost same which means there is no effect of textile sludge addition on the binder paste.

Table 4.2: Initial, Final Setting Time and Soundness of Binder Paste

Mix Designation	Initial setting time (min)	Final setting time (min)	Change in time (Δt)	Soundness (mm)
CM	110	235	125	1
TS5	116	249	133	1
TS10	134	271	137	1.5
TS15	155	300	145	2
TS20	175	325	150	2

4.2.3 Workability

Fluidity of paste containing textile sludge as a partial replacement of cement was measured with the help of marsh cone test. The effect of water/ binder ratio on textile sludge was studied. Results of control mortar (CM) and textile sludge mortar at various replacement percentages, and at three different water cement ratio of 0.46, 0.48, 0.5 are presented in Figure 4.1 and shown in Table 4.3. It can be observed flow time expressed in seconds was increasing as replacement of cement with textile sludge was increased. Moreover the flow time tends to decrease with increase in w/c ratio in each mortar mix. The decrease in flow time results in higher fluidity.

For the mix having water/binder ratio of 0.46, the flow time of the mixes is increasing with increase in replacement of cement by textile sludge. The flow time is increased for the binder paste by 21.05, 60.53, 123.08 and 156.58% for TS5, TS10, TS15, and TS20 compared to that of control mix. Similarly at water/binder ratio of 0.48 for TS 5, TS10, TS15, and TS20 the flow time is increased by 21.1, 94.92, 176.27 and 220.34% than that of control mix. At water/binder ratio of 0.5 for TS 5, TS10, TS15, and TS20 flow time is increased by 17, 47, 95 and 119%. It shows that upto 5% addition the textile sludge the fluidity remains closer to control mix. It has been also observed that the flow time increases with addition of textile sludge, this may be due to its higher specific surface area and adsorption capacity with cement. The water demand of textile sludge is also high as compared to that of cement which causes decrease in fluidity.

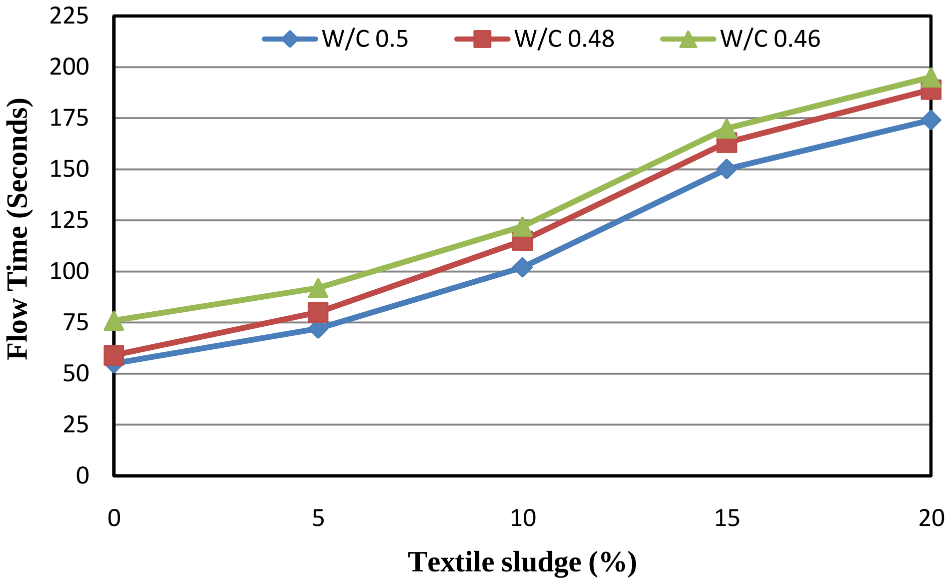

Fig. 4.1: Effects of Textile Sludge on Fluidity of Cement Paste

Table 4.3: Effects of Textile Sludge on Fluidity of Cement Paste

Mix Designation	Flow time (seconds)		
	W/B = 0.46	W/B = 0.48	W/B = 0.50
CM	76	59	55
TS5	92	80	72
TS10	122	115	102
TS15	170	163	150
TS20	195	189	174

4.3 Effect of Addition of Textile Sludge on Compressive Strength

The effect of addition of textile sludge on compressive strength of mortars mixes was studied at the age of 3, 7 and 28 days of testing. The results are presented in Figure 4.2 and shown in Table 4.4. It can be observed that compressive strength of mortar mix with 5% textile sludge was found to be comparable to control mortar at all ages of testing. However at higher replacement level of 10% and above these was a considerable decrease in compressive strength of cement sludge mortar mixes as compared to control mortar. Compressive strength of all the mortar mixes increase with age.

The average Compressive Strength at 28 days is maximum for the control mix (CM) 45.57 MPa and the mixes TS5, TS10, TS15, TS20 where 44.20 MPa, 41.04 MPa, 38.11 MPa and 30.20 MPa. At the age of 28 days the decrease in the compressive strength was 3, 9.97, 16.42 and 33.81% respectively. Also, the average Compressive Strength at 7 days is maximum for the control mix (CM) 34.67 MPa. Similarly the average compressive strength at 7 days for the mixes TS5, TS10 TS15, TS20 were 33.95 MPa, 31.42 MPa, 28.50 MPa and 24.61 MPa. At the age of 7 days the decrease in the compressive strength was 2.12, 9.54, 18.10 and 29.52% respectively for TS5, TS10, TS15 and TS20. The average compressive strength at 3 days for the control mixes (CM), TS5, TS10, TS15 and TS20 were 26.27 MPa, 25.27 MPa, 24.56 MPa, 24.08 MPa and 21.35 MPa. At the age of 3 days the decrease in the compressive strength was 1.44, 6.58, 8.43 and 18.91% respectively for TS5, TS10, TS15 and TS20.

The calcium oxide content of textile sludge is lesser than calcium oxide content of ordinary Portland cement so when we replace cement with equal amount of textile sludge net calcium oxide content of binder paste decreases which may slow down the hydration reaction and results in decrease in compressive strength of mortar. The decrease in compressive strength can be due to the increase in the water demand required for a given consistency. Also the strength reduction might be due to the presence of certain compounds like zinc, lead. The presence of these compounds has harmful effect on the hydration process. The compound may surround the cement particle and from membrane with formation of calcium hydroxylzincate ($CaZn_2(OH)_6.2H_2O$) that prevents the movement of water and ion required for hydration. The prevention of hydration process causes reduction in strength development.(Patel and Pandey 2012).

Moreover, the strength reduction is due to decrease in specific gravity of textile sludge as compared to cement.

It can be observed that replacement of cement with 5% textile sludge does not affect the compressive strength much i.e. compressive strength of control mix and TS5 are almost equal. However for all other mix the strength reduces sharply. Similar trend of compressive strength was also reported by Balasubramanian et al. 2006.

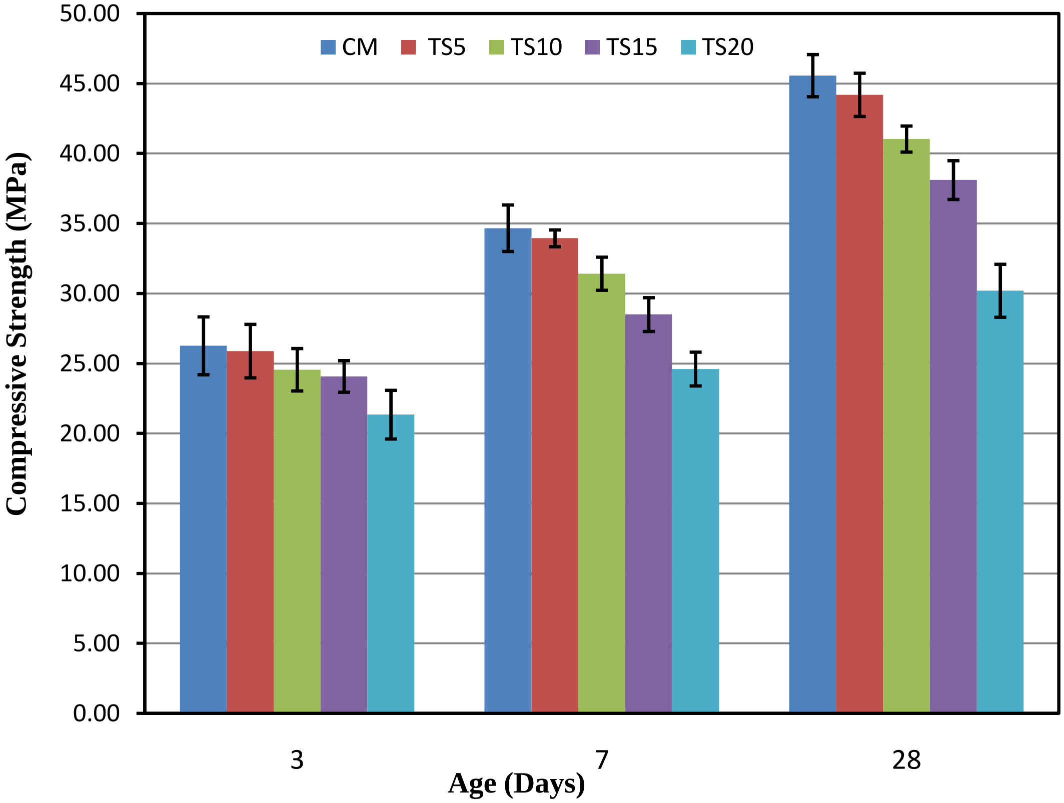

Fig. 4.2: Compressive Strength Test Results of Textile Sludge Mortar

Table 4.4: Compressive Strength Test Results of Mortar Mixes with Textile Sludge

Mix Designation	Compressive Strength (MPa)			Average Compressive Strength (MPa)		
	3 days	7 days	28 days	3 days	7 days	28 days
CM	26.28	33.42	47.11	26.27	34.67	45.57
	28.33	36.55	45.50			
	24.20	34.03	44.10			
TS5	24.60	34.19	43.42	25.89	33.95	44.20
	25.00	34.39	45.98			
	28.09	33.26	43.22			
TS10	26.16	30.05	41.65	24.56	31.42	41.04
	24.36	32.06	39.97			
	23.15	32.14	41.49			
TS15	25.36	29.85	39.52	24.08	28.5	38.11
	23.63	27.53	38.04			
	23.23	28.13	36.75			
TS20	21.11	23.83	32.18	21.35	24.61	30.20
	19.74	24.00	28.41			
	23.19	26.00	30.01			

4.4 Effect of Addition of Textile Sludge on Split Tensile Strength

The effect of addition of textile sludge on split tensile strength of mortars mixes was studied at the age of 7, 14 and 28 days of testing. The results are presented in Figure 4.3 and shown in Table 4.5. It can be observed that split tensile strength of mortar mix with 5% textile sludge was found to be comparable to control mortar at all ages of testing. However at higher replacement level of 10% and above these was a considerable decrease in split tensile strength of cement sludge mortar mixes as compared to control mortar.

The average split tensile strength at 28 days is maximum for the control mix (CM) 4.02 MPa and the mixes TS5, TS10, TS15 and TS20 where 3.82 MPa, 3.36 MPa, 3.05MPa and 2.26 MPa. At the age of 28 days the decrease in the split tensile strength was 4.98, 16.42, 24.13 and 43.78% respectively for TS5, TS10, TS15 and TS20. Also, the average split tensile strength at 14 days is maximum for the control mix (CM) 3.48 MPa. Similarly the average strength split tensile strength at 14 days for the mixes TS5, TS10, TS15 and TS20 were 3.37 MPa, 3.03 MPa, 2.73 MPa and 2.04 MPa. At the age of 14 days the decrease in the split tensile strength was 3.16, 12.93, 21.55 and 41.38% respectively for TS5, TS10, TS15 and TS20. The average split tensile strength at 7 days for the control mixes (CM), TS5, TS10, TS15 and TS20 were 2.91 MPa, 2.79 MPa, 2.37 MPa, 2.36 MPa and 1.93 MPa. At the age of 7 days the decrease in the split tensile strength was 4.12, 18.56, 20.27 and 33.68% respectively for TS5, TS10, TS15 and TS20. Similar reasons can be listed out in this case as that of compressive strength.

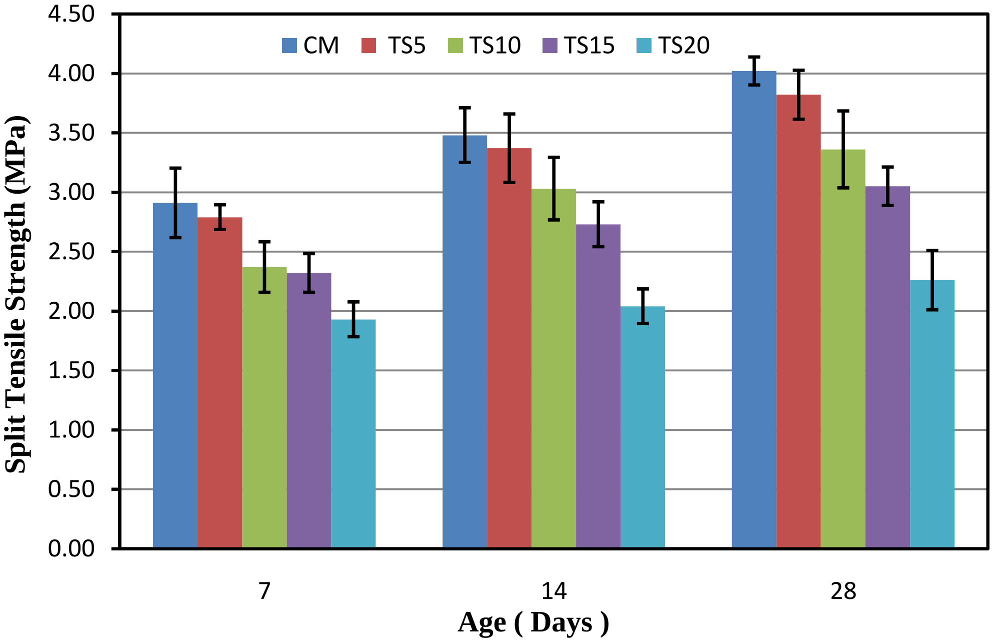

Fig. 4.3: Split Tensile Strength Test Results of Textile Sludge Mortar

Table 4.5: Split Tensile Strength Test Results of Mortar Mixes with Textile Sludge

Mix Designation	Split Tensile Strength (MPa)			Average Split Tensile Strength (MPa)		
	7 days	14 days	28 days	7 days	14 days	28 days
CM	2.81	3.45	4.02	2.91	3.48	4.02
	3.25	3.27	4.20			
	2.66	3.73	3.85			
TS5	2.48	3.21	3.75	2.79	3.37	3.82
	2.89	3.70	3.66			
	3.00	3.21	4.04			
TS10	2.10	2.83	3.60	2.37	3.03	3.36
	2.71	3.33	3.35			
	2.31	2.93	3.14			
TS15	2.48	2.52	2.85	2.32	2.73	3.05
	2.08	2.87	3.23			
	2.39	2.81	2.98			
TS20	1.87	2.19	2.33	1.93	2.04	2.26
	1.81	1.89	2.48			
	2.10	2.04	1.98			

4.5 Effect of Addition of Textile Sludge on Water Absorption

The water absorption in mortar plays an important role in the durability. The amount of water absorption is related to capillary forces exerted by pore structure of mortar, to entrap the fluids in water into the mortar. The water absorption test was conducted at age of 7 days after initial curing of 28 days and at the age of 28 days after initial curing of 28 days. The results of water absorption are presented in Figure 4.4 and shown in Table 4.6, Table 4.7. Water absorption goes on increasing with increase in replacement of cement with textile sludge at all specified ages of testing. Moreover water absorption at 28 days was found to be less than water absorption of 7 days in all mortar mixes.

The result of water absorption observed at the age of 7 days after initial using of 28 days shows that the water absorption is minimum for the control mix (CM) i.e. 3.06% and for mix TS5, TS10, TS15 and TS 20 were 3.10, 3.33 and 3.52% respectively. The water absorption was found to be increased by 4, 16, 27 and 46% for TS5, TS10, TS15 and TS20 as compared to the control mix. Similarly the results of water absorption observed at age of 28 days after initial curing of 28 days shows that the water absorption is minimum for the control mix (CM) i.e. 2.15% and other mixes TS5, TS10, TS15 and TS20 were 2.18, 2.25, 2.40and 2.73% respectively. The water absorption was found to be increased by 3, 10, 25 and 33% respectively. It is clear that with increase in textile sludge content workability of mortar goes on decreasing which may have lead to improper compaction resulting porous microstructure as compared to control mortar leads to increase in voids which causes increase in water absorption.

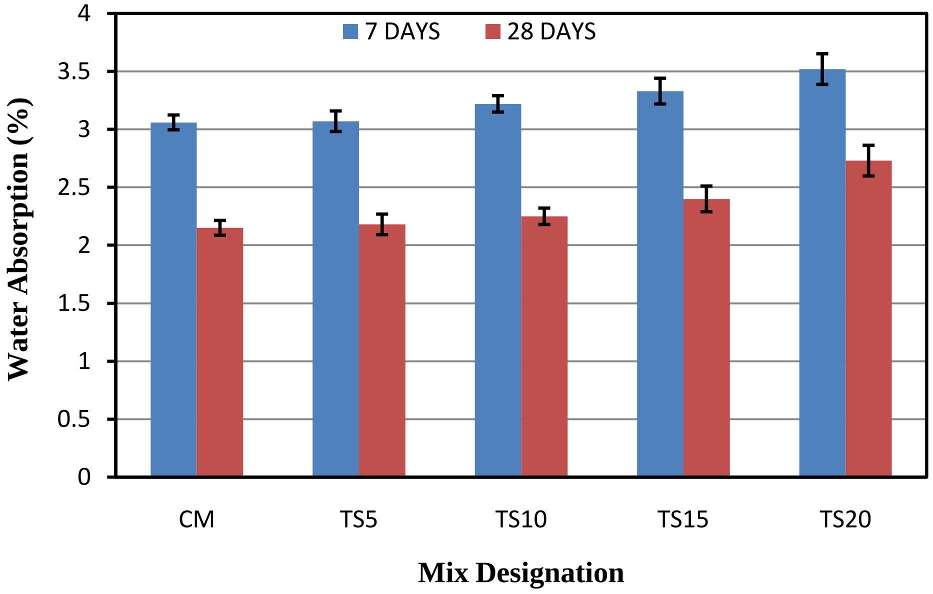

Fig. 4.4: Water Absorption of Textile Sludge Mortar

Table 4.6: Water Absorption 7 Days after Initial Curing of 28 Days of Mortar Mixes with Textile Sludge

Mix Designation	Weight of Cube after 24 hour Oven Drying, W_1(gm)	Weight of Cube After 96 hour Immersion in Water, W_2 (gm)	Water Absorption (%) = $W_2W_1)/W_1*100$	Average Water Absorption (%)
CM	795	819	3.02	3.06
	792	816	3.03	
	797.5	822.5	3.13	
TS5	766	789	3.00	3.07
	775	800	3.23	
	784.5	808	3.00	
TS10	759	783.5	3.23	3.22
	748	771.5	3.14	
	746.5	771	3.28	
TS15	741.5	766	3.30	3.33
	752.5	778.5	3.46	
	756.5	781	3.24	
TS20	757	784	3.57	3.52
	756	781.5	3.37	
	786	814.5	3.63	

Table 4.7: Water Absorption 28 days after Initial Curing of 28 Days of Mortar Mixes with Textile Sludge

Mix Designation	Weight of Cube after 24 hour Oven Drying, W_1(gm)	Weight of Cube After 96 hour Immersion in Water, W_2 (gm)	Water Absorption (%) = $(W_2-W_1)/W_1*100$	Average Water Absorption (%)
CM	805.5	821	1.92	2.15
	785	804	2.42	
	806	823	2.11	
TS5	810.5	826.5	1.97	2.18
	767.5	786	2.41	
	786	803	2.16	
TS10	792.5	810	2.21	2.25
	774	791	2.20	
	748	765.5	2.34	
TS15	781.5	800	2.37	2.40
	774	791	2.20	
	761	781	2.63	
TS20	760.5	785	3.22	2.73
	784	803.5	2.49	
	766.5	785.5	2.48	

4.6 Effect of Addition of Textile Sludge on Rapid Chloride-ion Permeability

Rapid chloride-ion permeability test is related to the pore structure of the concrete and mortar. It measures the chloride-ion penetration into concrete and mortar. According to the charge passed in coulombs, through the sample a qualitative rating is done. The result of textile sludge mortar on chloride-ion permeability test is presented in Figure 4.5 and shown in Table 4.8. It can be observed that average charged passed in rapid chloride-ion permeability test for mortar mix with 5% textile sludge was found to be lesser than control mortar. However for higher replacement level of 15% and above there is increase in rapid chloride-ion permeability as compared to control mortar.

At the age of 28 days the amount of charge passed in coulomb were 3003, 2703, 2939, 3511 3967 respectively for control mix, TS5, TS10, TS15, TS20. According to ASTM C 1202 all mortar mixes have moderate permeability to chloride-ion. The decrease in the charge passed in coulomb for TS5 compare to control mix (CM) is because of the fact that textile sludge is finner in compare to cement and it tends to fill up the voids more accurately as compare to cement. At TS5 replacement it leads to fill up the voids more accurately as compare to cement. Also TS5, replacement it leads to the refinement of pore structure of mortar which may be the reason for lower chloride-ion penetration. The increase in charge passed at higher replacement 15 and 20% may be due to decrease in compressive strength.

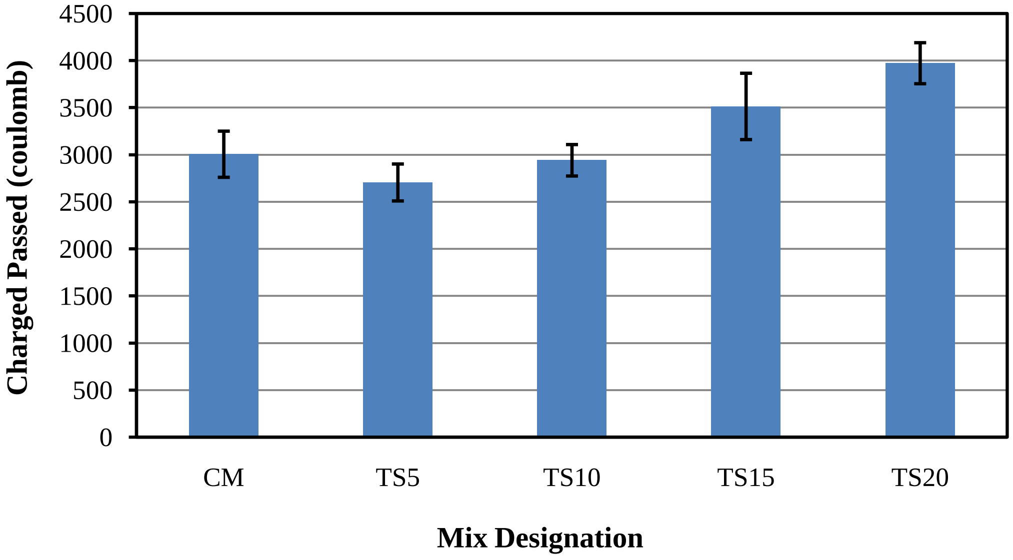

Fig. 4.5: Rapid Chloride-ion permeability Test Results of Textile Sludge Mortar at 28 Days

Table 4.8: Rapid Chloride-ion permeability Test Results of Textile Sludge Mortar

Mix Designation	Total Charge Passed at 28 days(coulombs)	Average Charge Passed (coulombs)	Chloride-ion Permeability as per ASTMC-1202
CM	3254	3003	Moderate
	2992		
	2764		
TS5	2869	2703	Moderate
	2486		
	2753		
TS10	3131	2939	Moderate
	2855		
	2830		
TS15	3168	3511	Moderate
	3492		
	3872		
TS20	4213	3967	Moderate
	3798		
	3890		

4.7 Effect of Addition of Textile Sludge on Sorptivity of Mortar

The sorptivity is defined as property of porous material to absorb and transmit water by capillary action. It is time dependant test to determine the tendency of mortar to absorb water by capillarity. This test is based on Darcy’s law of unsaturated flow. The results of textile sludge mortar on sorptivity are presented in Figure 4.6 and shown in Table 4.9. It can be observed that upto 10% replacement of cement with textile sludge sorptivity of cement sludge mortar mixes was found to be comparable with control mortar. However for higher replacement level of 15% and above there was an increase in sorptivity of mortar as compared to control mortar.

The control mortar mix has greater resistance to water absorption by capillary action than mortar containing textile sludge. The sorptivity increases with increase in replacement of cement with textile sludge. The sorptivity of control mix is 0.06 and the sorptivity increases by 3.39, 10.17, 19.73 and 23.66% for TS 5, TS10, TS15, and TS20. The sorptivity increases due to decrease in size of capillary pores which allows more water to rise under capillary action. Also textile sludge tends to absorb more water which may be the reason behind increase in sorptivity.

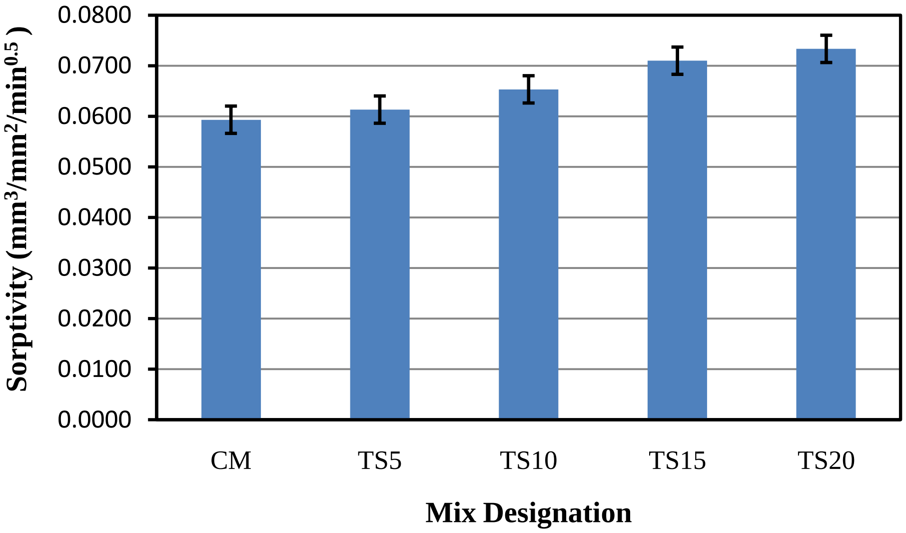

Figure 4.6: Sorptivity of Textile Sludge Mortar at 28 Days

Table 4.9: Sorptivty of Textile Sludge Mortar

Mix Designation	Sorptivity ($mm^3/mm^2/min^{0.5}$) at 28 Days	
	Individual	**Average**
CM	0.06	0.0600
	0.061	
	0.059	
TS5	0.061	0.0613
	0.062	
	0.061	
TS10	0.065	0.0673
	0.064	
	0.067	
TS15	0.07	0.0707
	0.072	
	0.07	
TS20	0.075	0.0733
	0.074	
	0.071	

4.8 Effect of Addition of Textile Sludge on Drying Shrinkage of Mortar

Shrinkage of mortar is the measurement of strain in the mortar with respect to time, in an unloading, unrestrained condition subjected to a constant temperature. Drying shrinkage in mortar occurs due to the loss of water head in the gel pores. The loss of water results in the change of dimension of specimen. The shrinkage of mortar lasts for a long period of time, till the specimen is subjected to the drying condition. The magnitude of shrinkage depends upon the fineness of the gel. The results of textile sludge mortar on drying shrinkage are presented in Figure 4.7 and shown in Table 4.10. It can be observed that increase in replacement of cement with textile sludge causes an increase in drying shrinkage at all specified ages of testing. Moreover for each mortar mix drying shrinkage goes on increasing with age. However this increase in shrinkage is more significant upto 28 days. After 28 days there is very small increase in shrinkage with age.

It has been observed that all the specimens shrinks in length with increase in time in days. The inclusion of textile sludge causes increase in shrinkage of mortar. The maximum shrinkage was observed for TS20 i.e. 1967 µm/m in 42 days, and 1478 µm/m, 1489 µm/m, 1556 µm/m, 1789 µm/m was observed for control mix (CM), TS5, TS10 and TS15. Drying shrinkage is a property of specific surface area of the binder (keeping all other parameters constant), so inclusion of textile sludge leads to increase in specific surface area of binder due to its higher fineness than cement thus with increase in replacement level there is an increase in drying shrinkage of mortar. With the inclusion of textile sludge in mortar, the water requirement for the standard consistency increases, which results increase in the amount of water in gel pores. Upon drying the gel, water gets lost over a long period of time causing an increase of shrinkage.

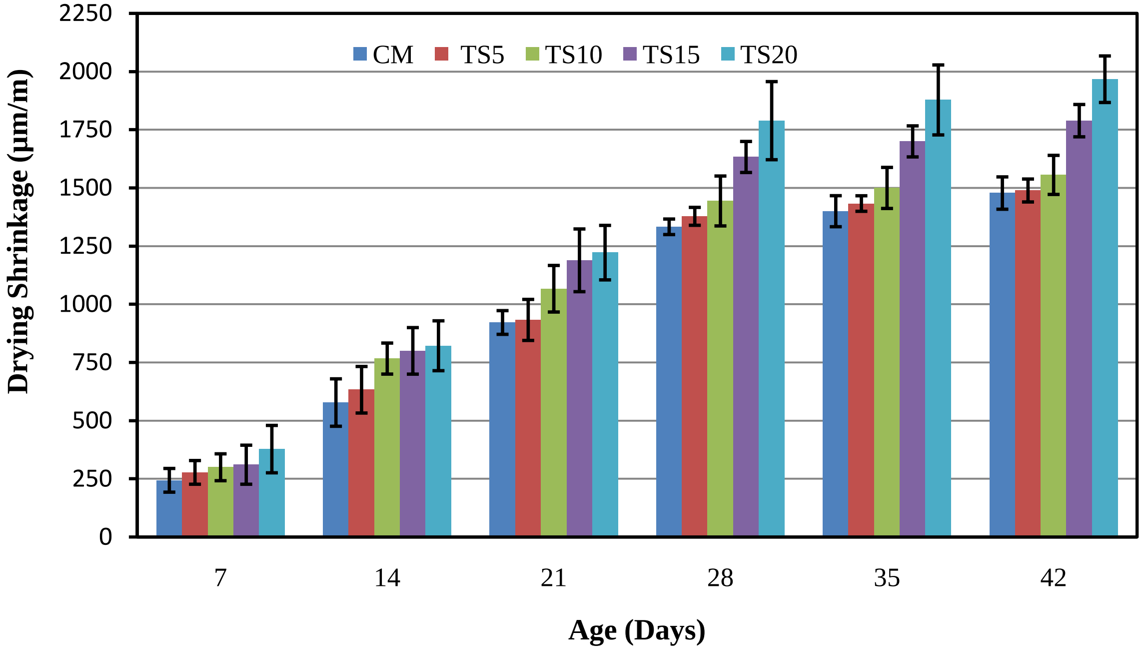

Figure 4.7: Drying Shrinkage of Textile Sludge Mortar

Table 4.10: Drying Shrinkage of Textile Sludge Mortar

Age (Days)	Average Shrinkage Strain in (µm/m) for Mixes				
	CM	**TS5**	**TS10**	**TS15**	**TS20**
7	244	278	300	311	378
14	578	633	767	800	822
21	922	933	1067	1189	1222
28	1333	1378	1444	1633	1789
35	1400	1433	1500	1700	1878
42	1478	1489	1556	1789	1967

4.9 X-ray Diffraction (XRD) of Control and Textile Sludge Mortar

The X-ray diffraction were performed to study the quantative phase formation of cement and textile sludge moratrs.The control mix and the mixes with replacement of cement with textile sludge i.e.TS5, TS10, TS15 and TS20 was studied. The test were performed after initial curing of

28 days. The XRD test were performed for diffracation angle of 2Θ at a spacing of 10º to 70º in the steps of 2Θ = 0.013º. The XRD of contol mix, TS5, TS10, TS15 and TS20 are presented in Figure 4.8, 4.9, 4.10, 4.11 and 4.12.

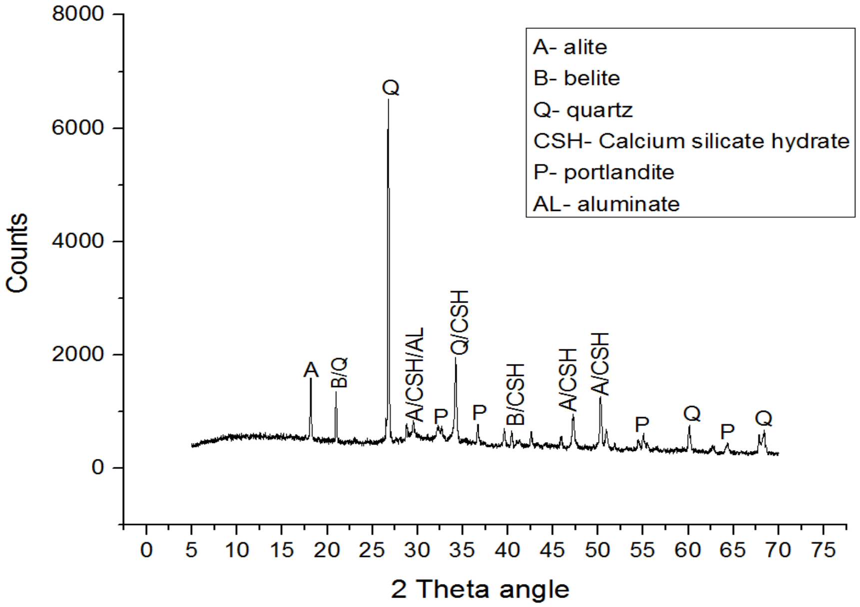

Fig. 4.8: X-ray Diffraction Pattern of Control Cement Mortar

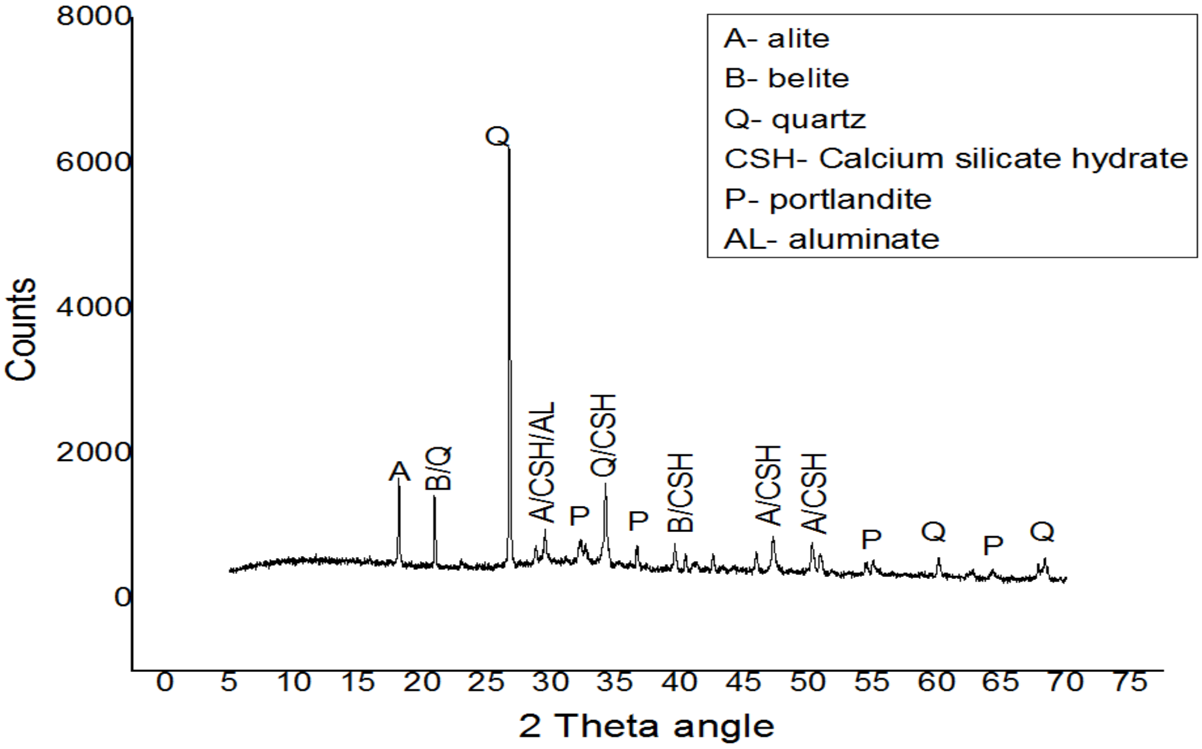

Fig.4.9: X-ray Diffraction Pattern of Cement Mortar Containing 5% Textile Sludge

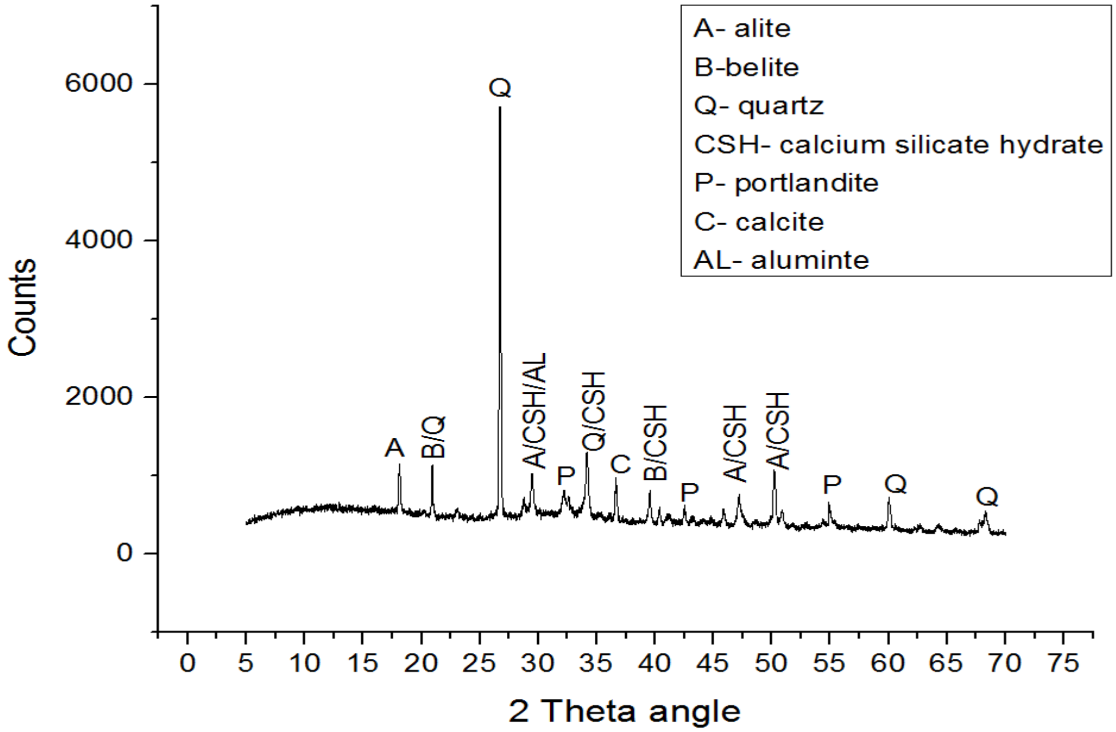

Fig. 4.10: X-ray Diffraction Pattern of Cement Mortar Containing 10% Textile sludge

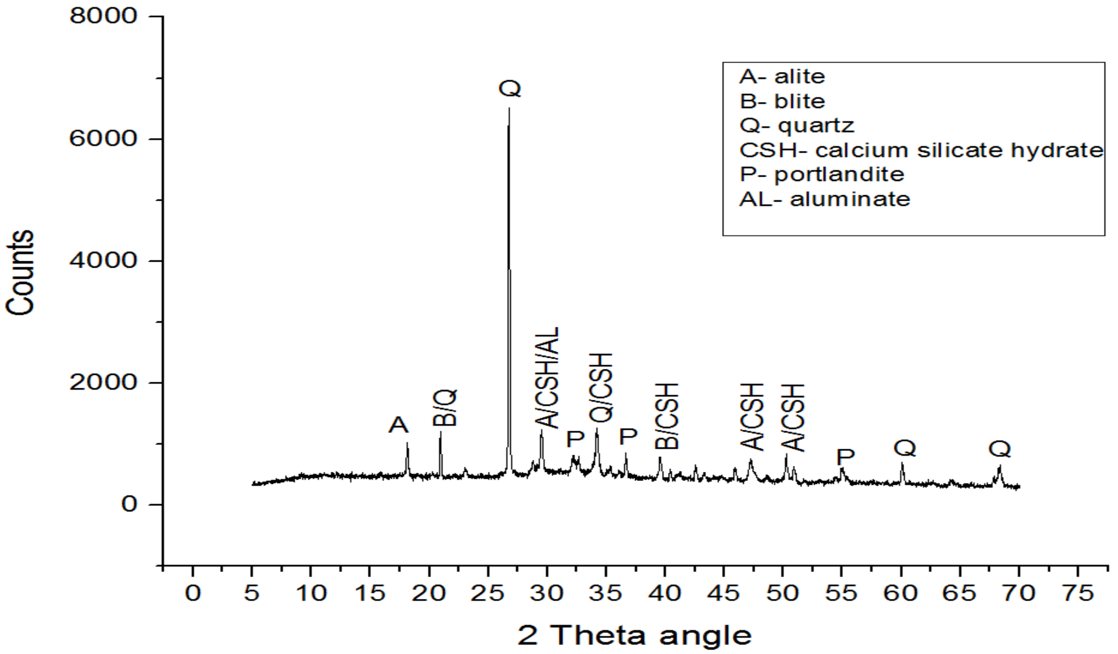

Fig. 4.11: X-ray Diffraction Pattern of Cement Mortar Containing 15% Textile Sludge

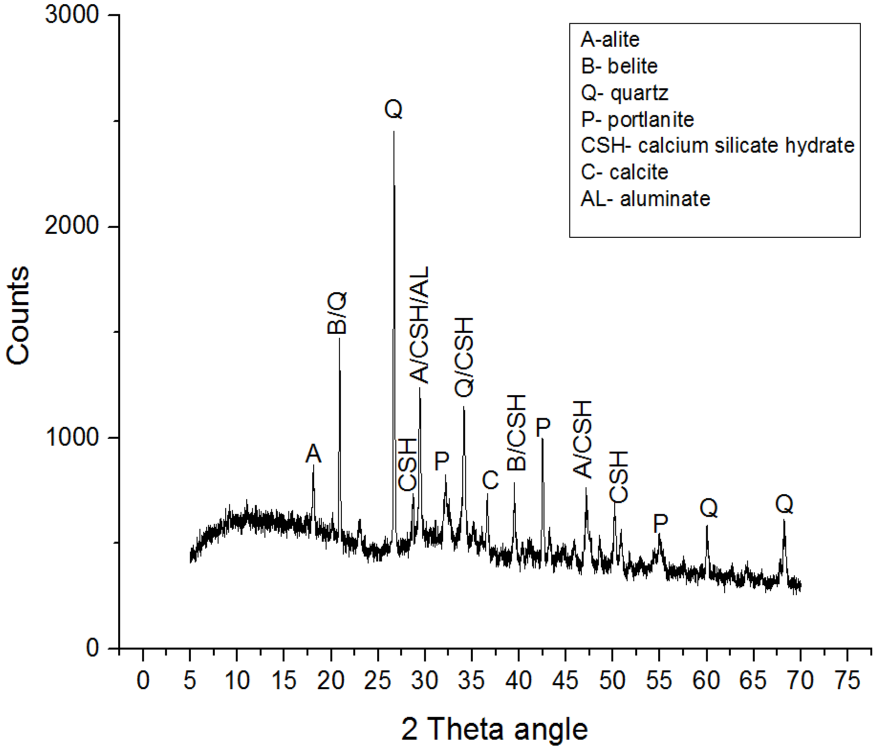

Fig. 4.12: X-ray Diffraction Pattern of Cement Mortar Containing 20% Textile Sludge

The major phases present in the motar were alite, belite, calium silicate hydrate, portlandite, aluminate, calcite, quartz. X-ray diffraction shows that there is no qualitative phase change in various phases of cement with textile sludge. There is only the quantative change in diffraction peaks and the peaks are reducing with the increase textile sludge content.Thus inclusion of textile sludge as a partial replacement of cement in mortar have no significant influence on the formation of cement hydration products i.e. textile sludge is an inert material.

4.10 Scanning Electron Microscopy of Texitile Sludge Mortar

The scanning electron microscopy of mortars (SEM) incorporating textile sludge as a partial replacement of cement and control mix were studied. The pieces of mortar mixes during compressive strength tes were taken for micristructure analysis. The microstructure shows the formation of calcium silicate hydrate gel, voids, portlandite and ettringite. Figure 4.13 shows the scanning electron micrograph of control cement mortars. The micrograph shows that calcium silicate hydrate gel is densly compacted and distributed throghout the complete area of images. No voids are present on the SEM images.

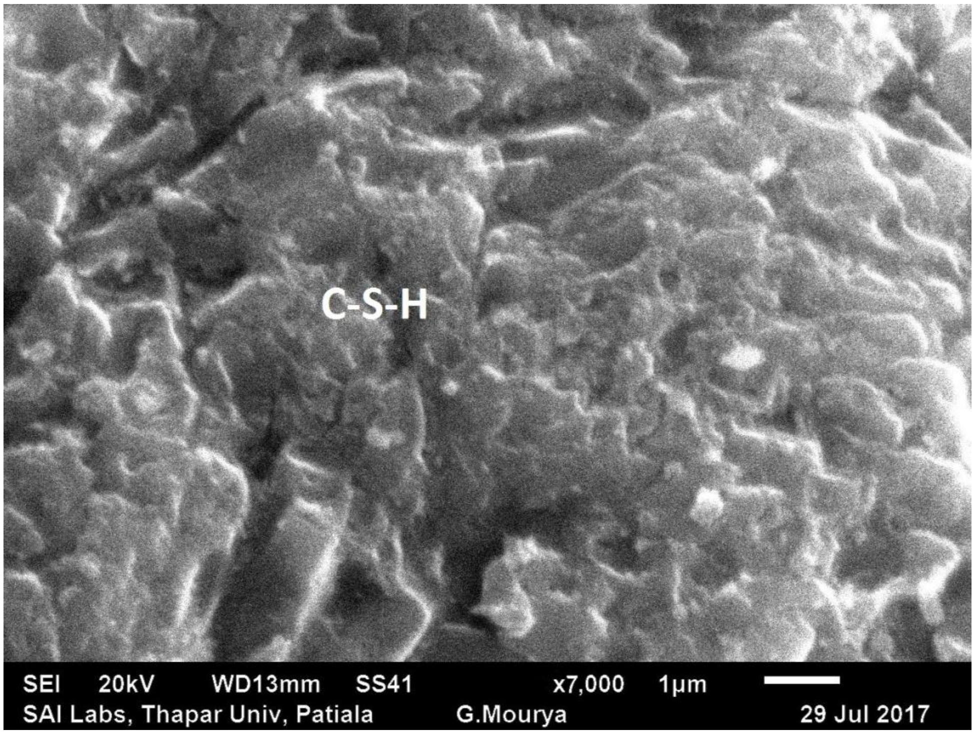

Fig. 4.13: SEM Morphology of Control Cement Mortar

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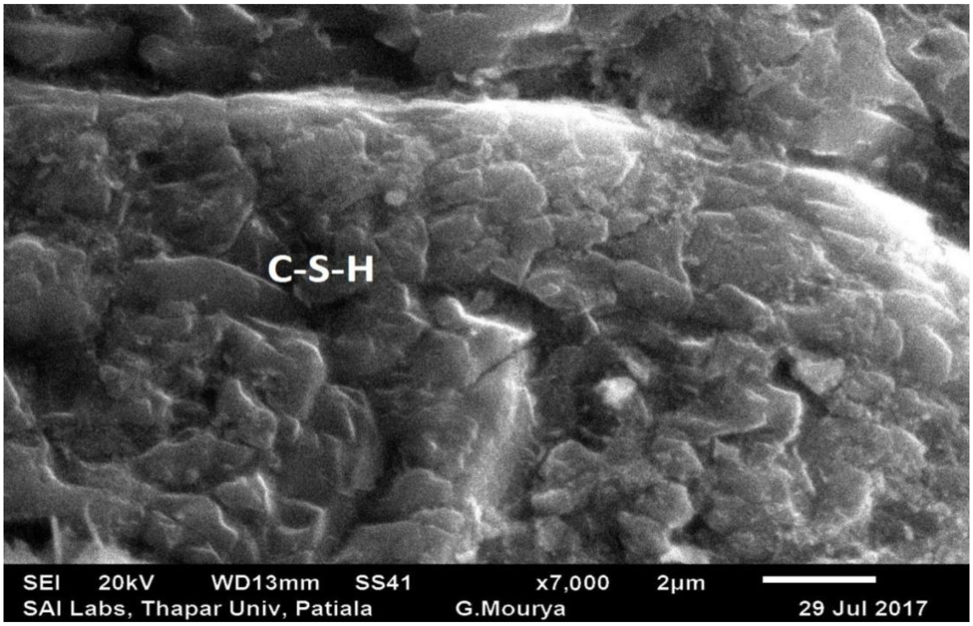

Fig. 4.14: SEM Morphology of Cement Replacement by 5% Textile Sludge Mortar

Figure 4.14 shows the SEM micrograph of cement replacement with 5% textile sludge. Equant grain type structure of calcium silicate hydrate was seen.

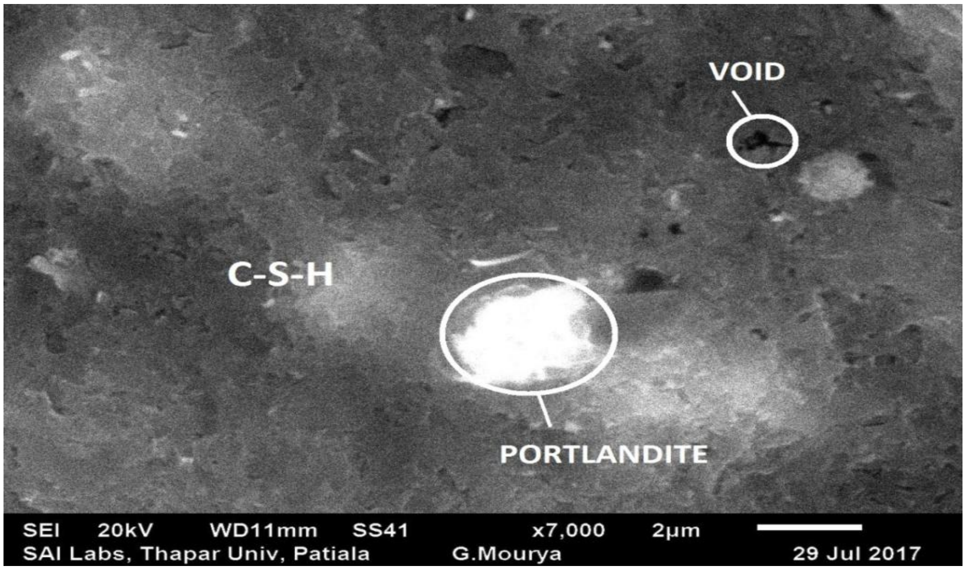

Fig. 4.15: SEM Morphology of Cement Replacement by 10% Textile Sludge Mortar

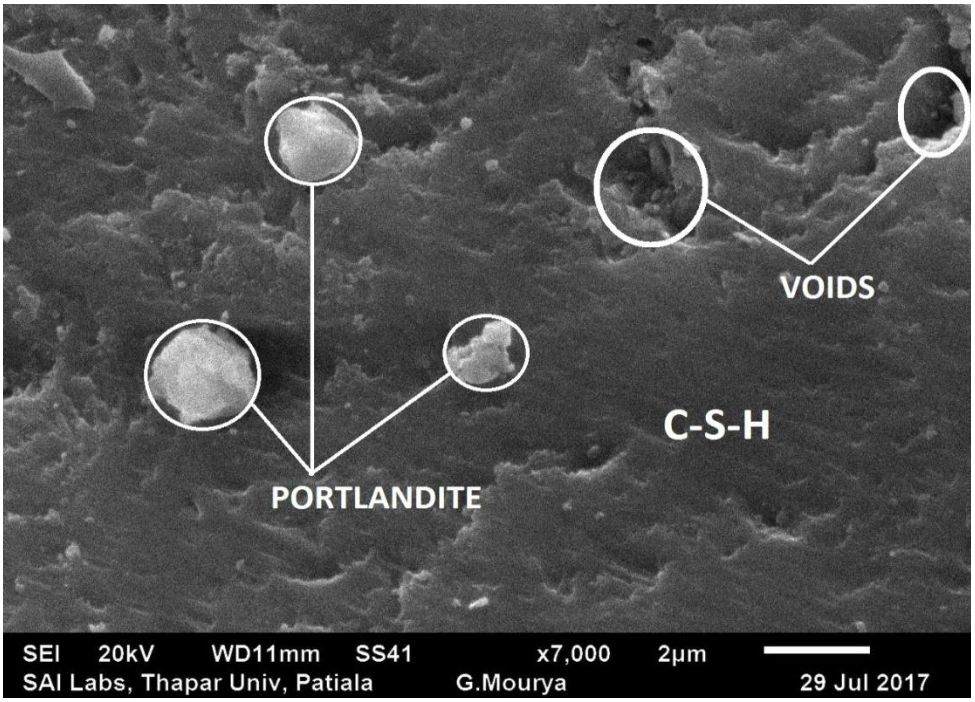

Fig. 4.16: SEM Morphology of Cement Replacement by 15% Textile Sludge Mortar

Figure 4.15 and 4.16 shows SEM micrograph of cement replacement with 10 and 15% textile sludge. The amount of unhydrated cement grain increases. There is also formation of voids. As the portlandite being most soluble of the hydration product and is weak link in mortar from durability aspect. When the paste comes in contact to fresh water the portlandite gets dissolved and there is an increase in porosity thus it leads to deteriotion of mortar.

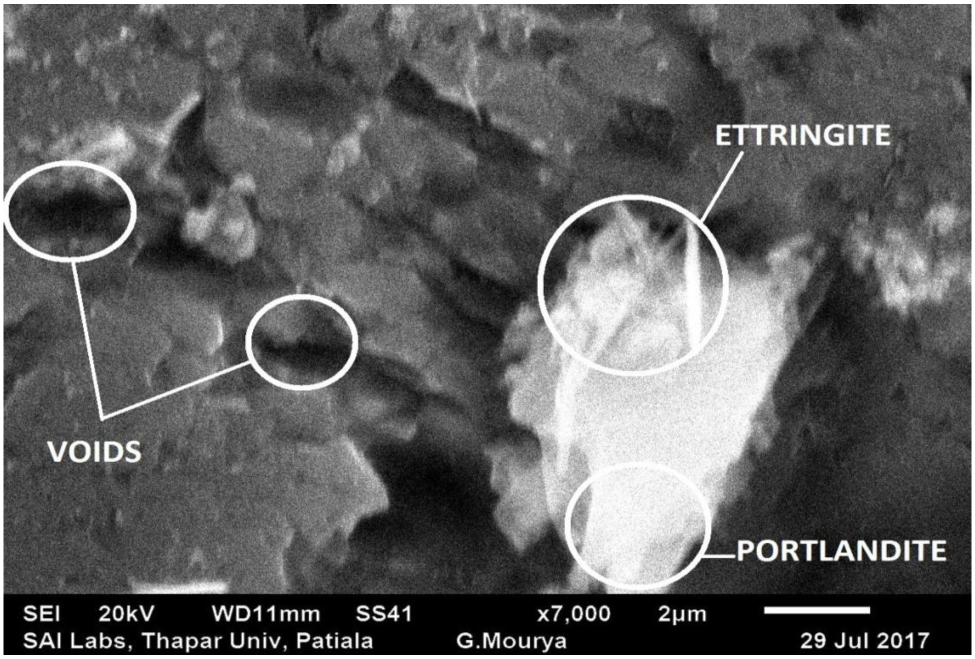

Fig. 4.17: SEM Morphology of Cement Replacement by 20% Textile Sludge Mortar

Figure 4.17 shows the SEM micrograph of cement replacement with 20% textile sludge. Slender needles of ettringite are present. There is an increase in the number of voids. The fibrous crystals are also present in the micrograph which shows there is delay in hydration reaction.

From the compressive strength test results of textile sludge incorporated mortars it shows that there is decrease in strength with increase in replacement level of textile sludge. The decrease in strength is due to formation of weak microstructure, increase in voids and decrease in net calcium silicate hydrate gel formation as compared to the control mix.

CHAPTER 5

CONCLUSIONS

5.1 General

The present experimental investigation was conducted to study the possibility of utilization of textile sludge as a partial replacement of cement in mortar. Various fresh properties (standard consistency, initial, final setting time and soundness of binder paste, workability), hardened properties (compressive strength and split tensile strength) and durability properties (Water absorption, rapid chloride-ion permeability, sorptivity and drying shrinkage) of mortar were tested by replacing cement with textile sludge at different varying percentages. XRD and SEM analysis was also done on all mortar mixes to study changes in cement phases as well as microstructure of mortar with inclusion of textile sludge as partial replacement of cement.

5.2 Conclusions

1) The standard consistency of cement sludge pastes goes on increasing with inclusion of textile sludge due to more water demand of textile sludge as compared to cement.
2) Initial setting time and final setting time of cement binder paste increases with the replacement of cement with textile sludge. The reason may be because of the different in chemical composition of cement and textile sludge as textile sludge contains lesser amount of calcium oxide as compared to cement. The soundness of binder paste is not affected by addition of textile sludge as a partial replacement of cement. This indicates absence of free lime in textile sludge.
3) The fluidity of cement sludge paste goes on decreasing with increase in cement replacement level. This may be due to increase in the specific surface area of binder paste as textile sludge is finer in compared to cement.
4) The compressive strength of 5% textile sludge has compressive strength closer to the control mix. However, after 5% replacement level compressive strength decreases gradually as compared to control mix. The net calcium oxide content in the binder paste reduces with the addition of textile sludge as a replacement of cement. Also specific gravity of textile sludge is lower than cement.

5) There is increase in rapid chloride-ion penetration resistance when cement is replaced by 5% textile sludge. Moreover, replacement of cement by more than 10% textile sludge causes decrease in chloride-ion penetration resistance as compared to control mix. The greater fineness of textile sludge as compared to cement tends to make microstructure more denser at lower replacement level.
6) The water absorption increases with increase in replacement of cement by textile sludge. The water absorption at 28 days after initial curing of 28 days is lower than the water absorption at age of 7 days after initial curing of 28 days. As specific gravity of textile sludge is lesser than cement so it will tends to absorb more water due to comparatively porous microstructure.
7) Drying shrinkage goes on increasing with increase in cement replacement by textile sludge. The highest shrinkage occurred at 20% textile sludge. The drying shrinkage increased at higher replacement level due to increase in specific surface area. Drying shrinkage also increases with increase in age of textile sludge mortar.
8) The sorptivity increases with the replacement of cement with textile sludge. The sorptivity increases due to decrease in size of capillary pores which allows more water to rise under capillary action.
9) The X-ray diffraction pattern of control mix mortar and cement sludge mortar shows that no definite change in various phases of cement hydration products due to the addition of textile sludge. There is only the quantative change in diffraction peaks and the peaks are reducing with the increase textile sludge content thus textile sludge can be regarded as an inert material. Scanning electron micrograph shows that beyond 5% replacement of cement with textile sludge there is increase in the number of voids. The fibrous crystals are also present in the micrograph which shows there is delay in hydration reaction.
10) It can be concluded that 5% replacement of cement with textile sludge is found to be optimum which gives cement mortar with satisfactory fresh mechanical and durability properties.

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